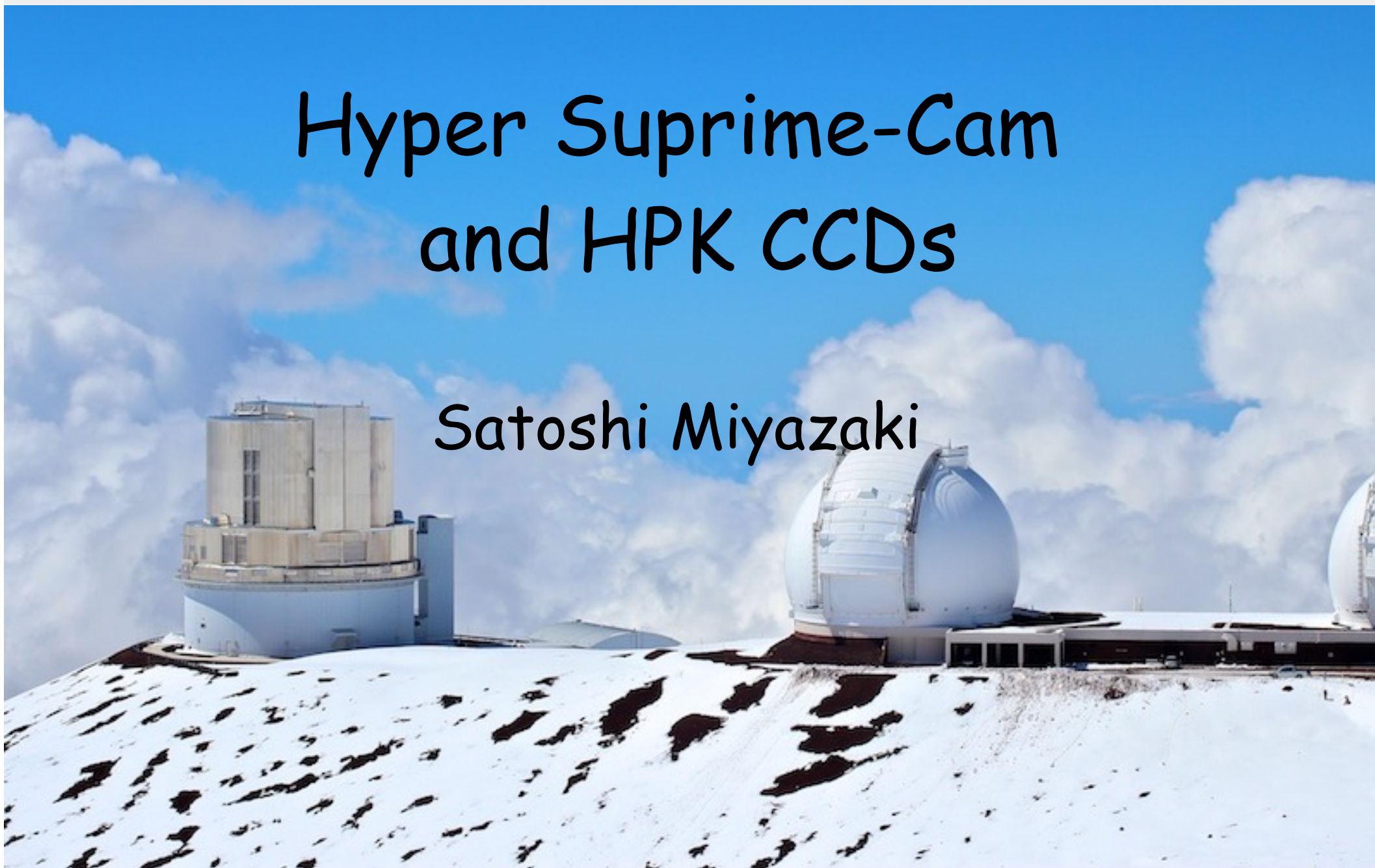


Hyper Suprime-Cam and HPK CCDs

Satoshi Miyazaki



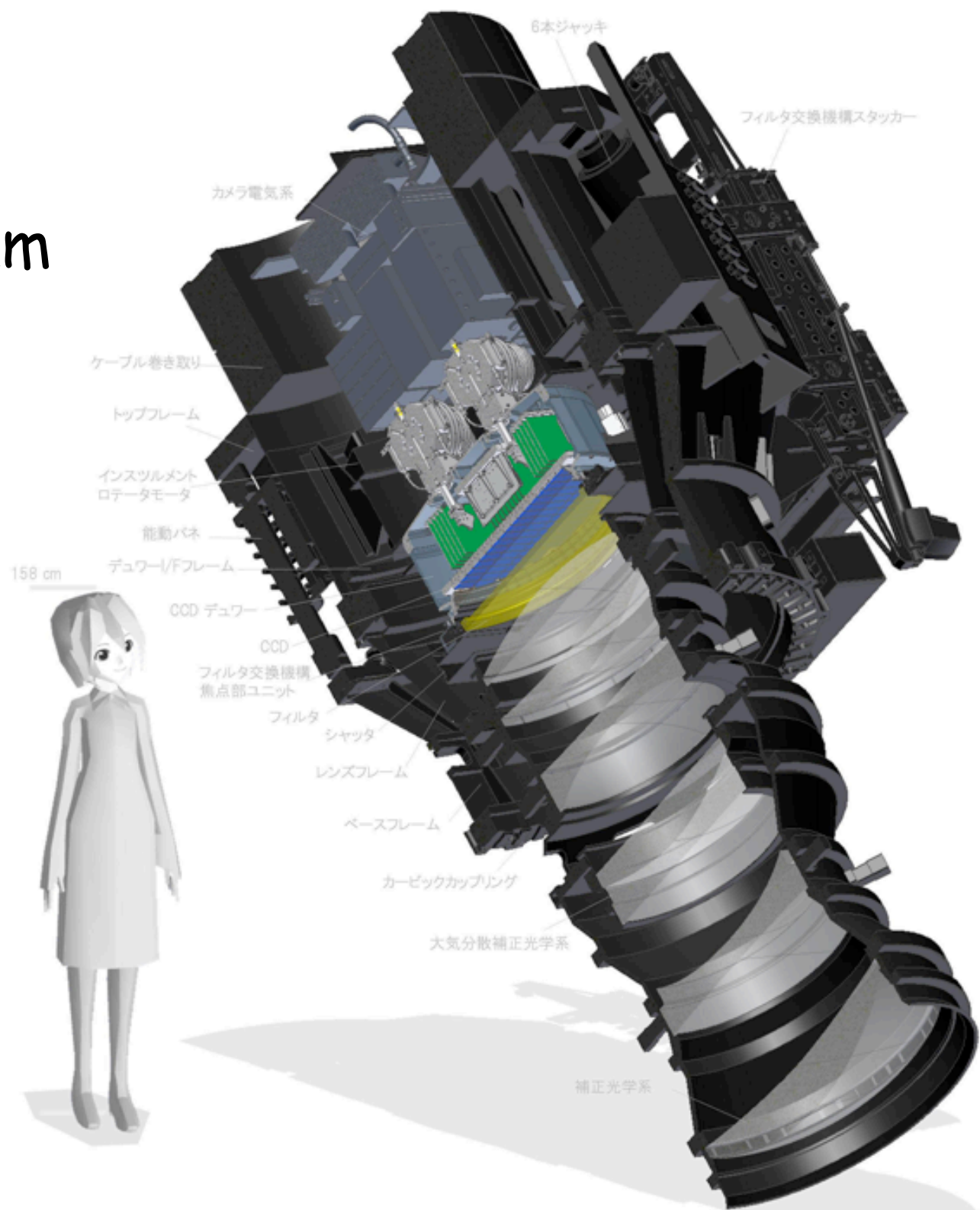


Hype Suprime-Cam

~ 10 G pixel
Digital Camera
for Subaru
Prime Focus

1.5 degree FOV

3 m high
~ 3 tons





Hyper Suprime-Cam Project

Academic Institutes

NAOJ

U-Tokyo(IPMU · Phys)

KEK

ASIAA

Princeton Univ.

Industrial Partner

Hamamatsu

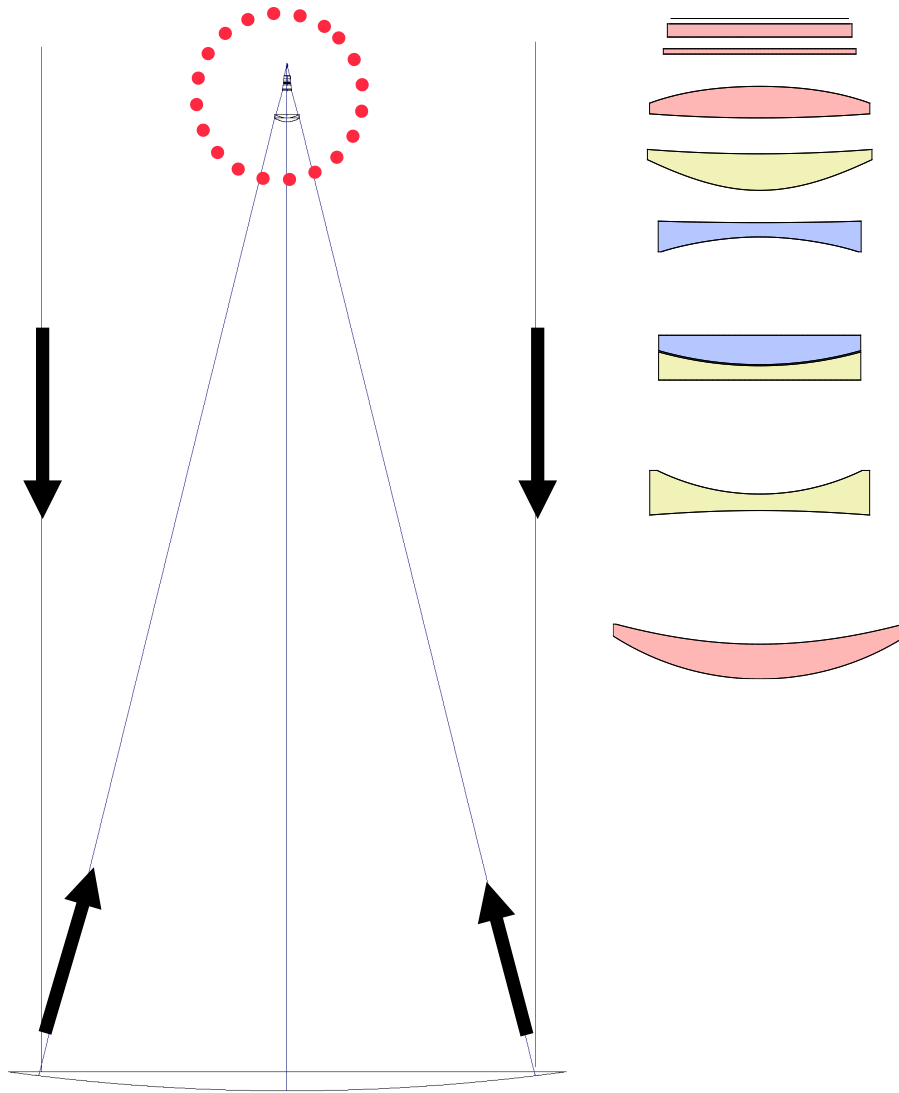
Canon

Mitsubishi Electric.

Key Elements

- Sharp Lens: $< 0''.2$ FWHM
- Large Number of CCDs
: to pave \varnothing 50 cm focal plane

HSC Optics



- 1 Aspheric mirror
- 7 element corrector
 - cf LSST
 - 3 Aspheric mirror
 - 4 element corrector

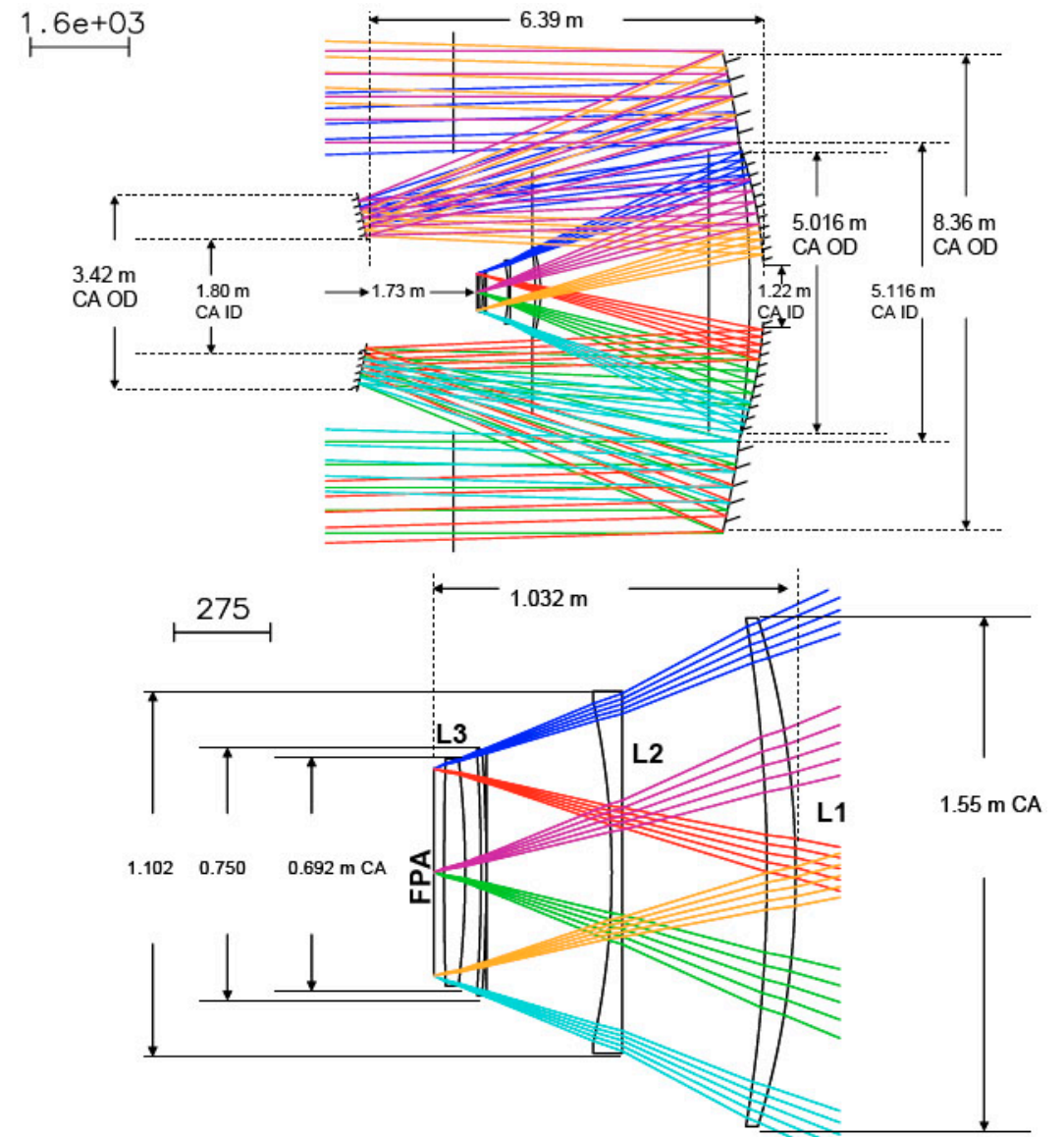
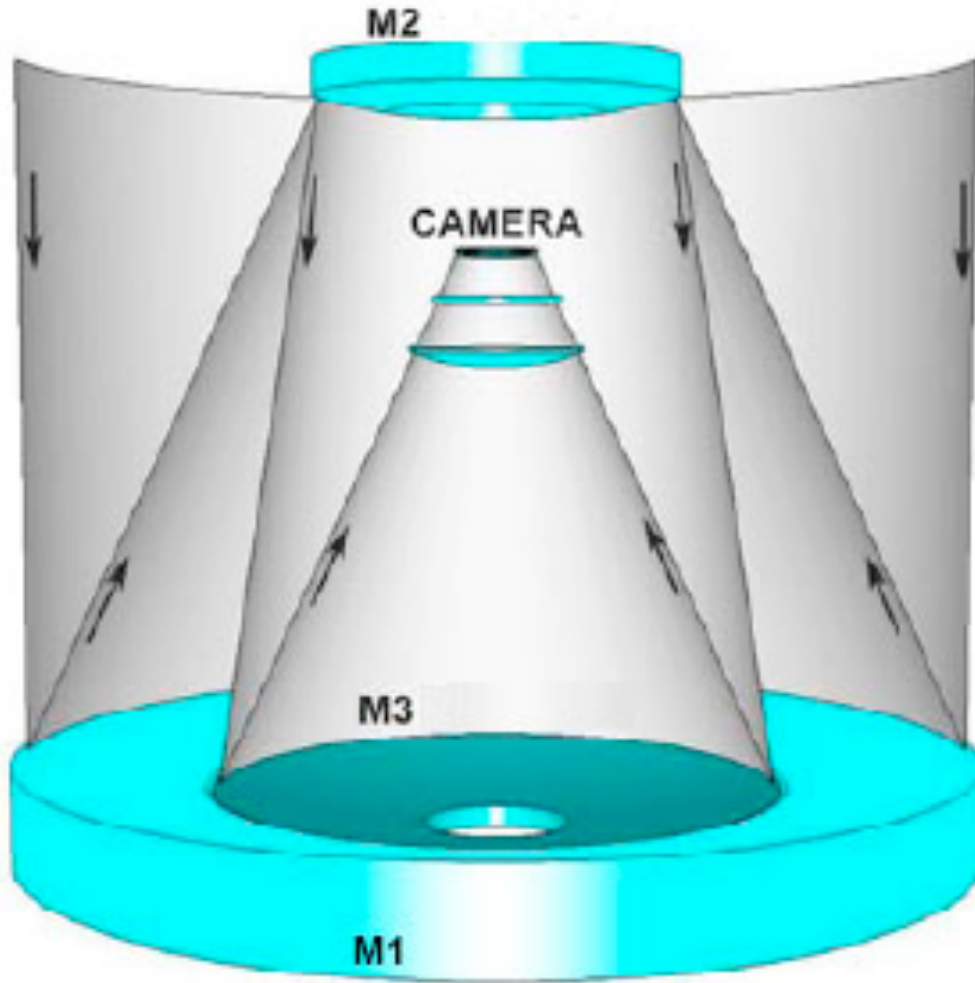
of surface:

LSST	11
HSC	15

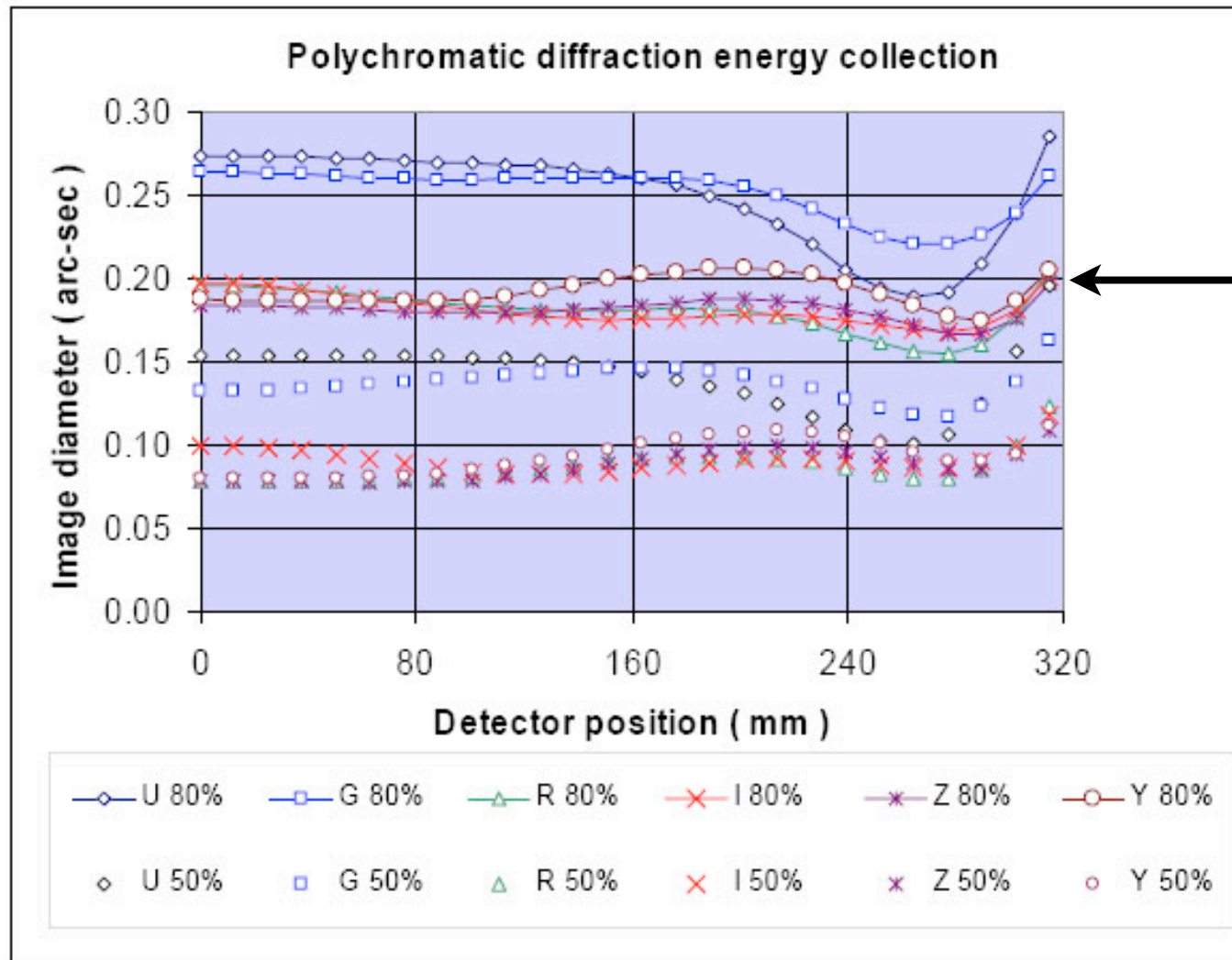
HSC:
Atmospheric
Dispersion
Corrector
implemented

LSST Optics

- 3 Aspheric mirror
- 4 element corrector



LSST Optics Design



Design Value

D80 = 0.2
arcsec

c.f.

HSC:

Design: 0".

15

Total: 0".3

D80: 80 % Encircled Energy
Diameter



CCDs

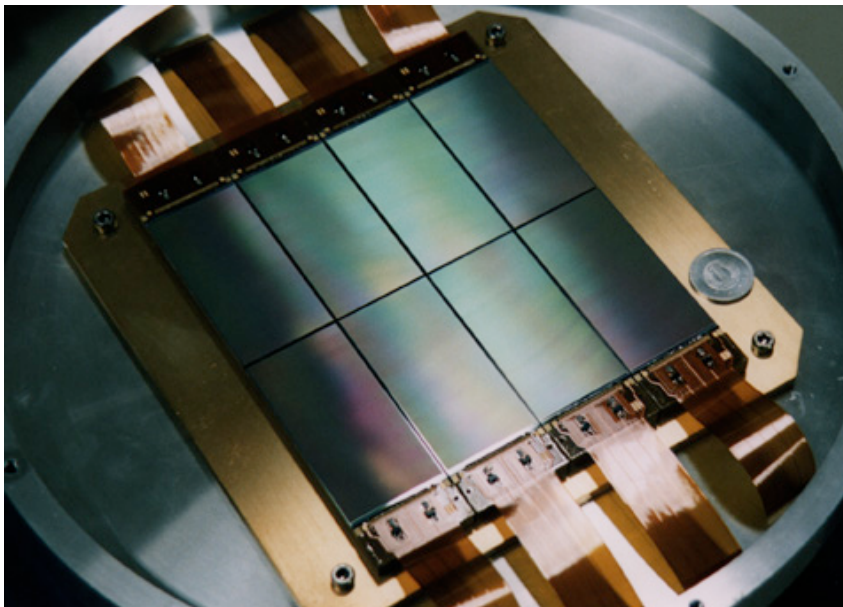


NAOJ-HPK Collaboration

1994 - 1996 Back Illuminated small CCD

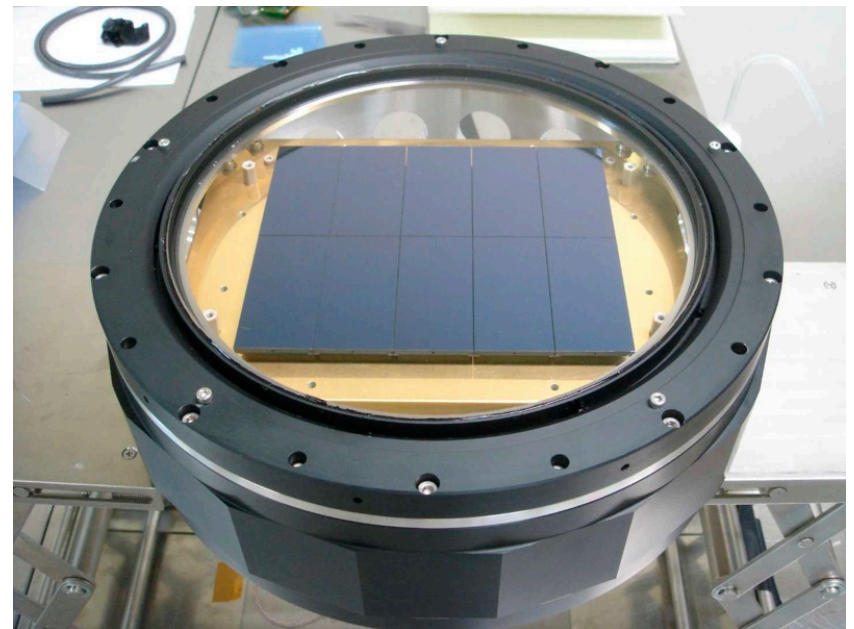
1996 - 1998 2k4k Front illuminated CCD

1999 - 2008 BI 2k4k Fully Depleted CCD



1998

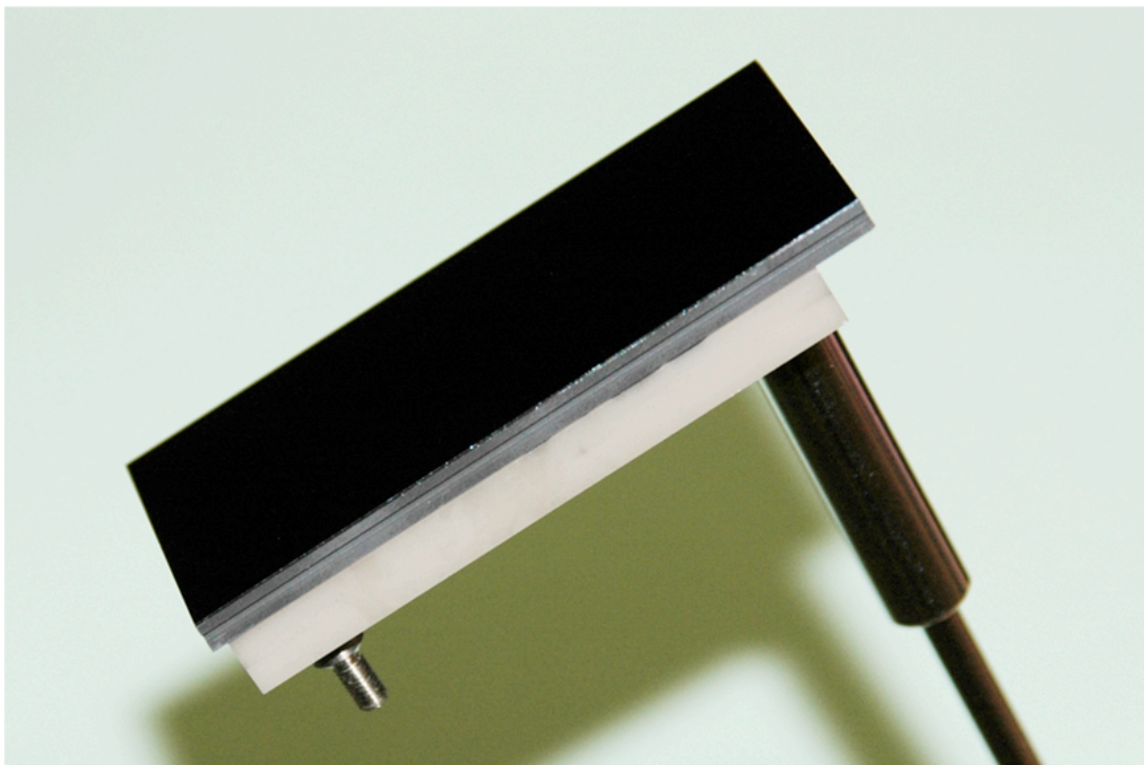
Satoshi Miyazaki



2008

HSC/NAOJ

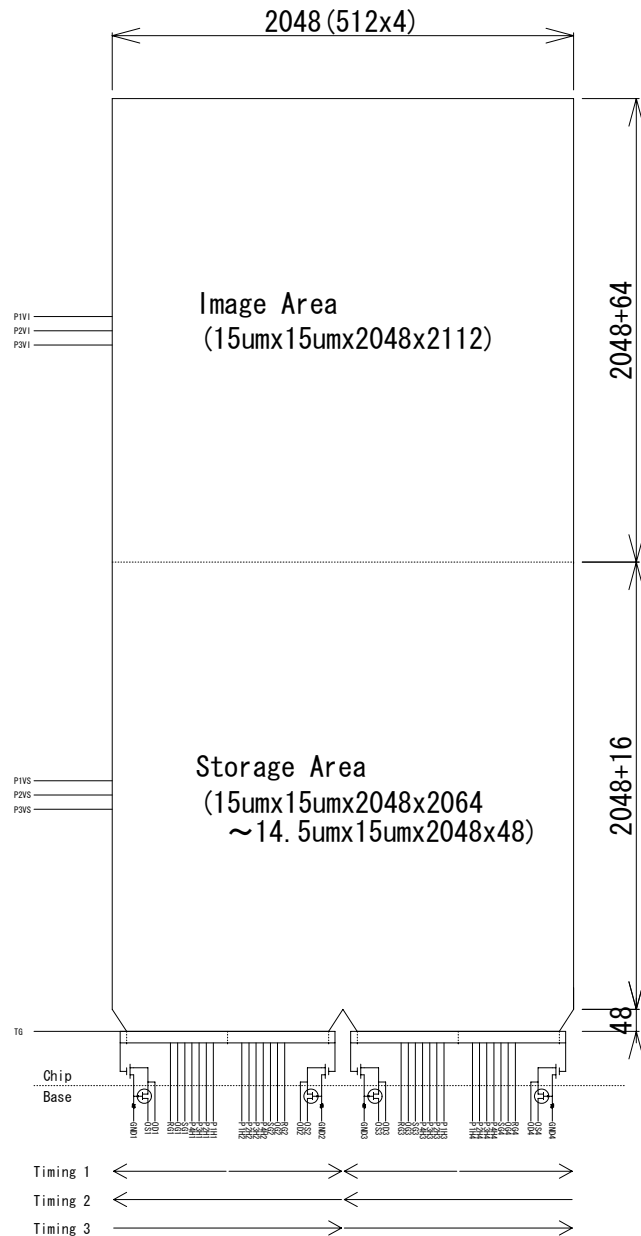
Collaboration with Hamamatsu



- 2k4k 15 μ m
- Fully depleted CCD
- High resistivity Si
- 200 μ m thick



HPK Fully Depleted CCD



CCD Structure

Si Thickness

Vertical clock phase

Horizontal clock phase

Output Amplifiers

Full Frame Transfer

200 μm (Can be 100 ~ 300 μm)

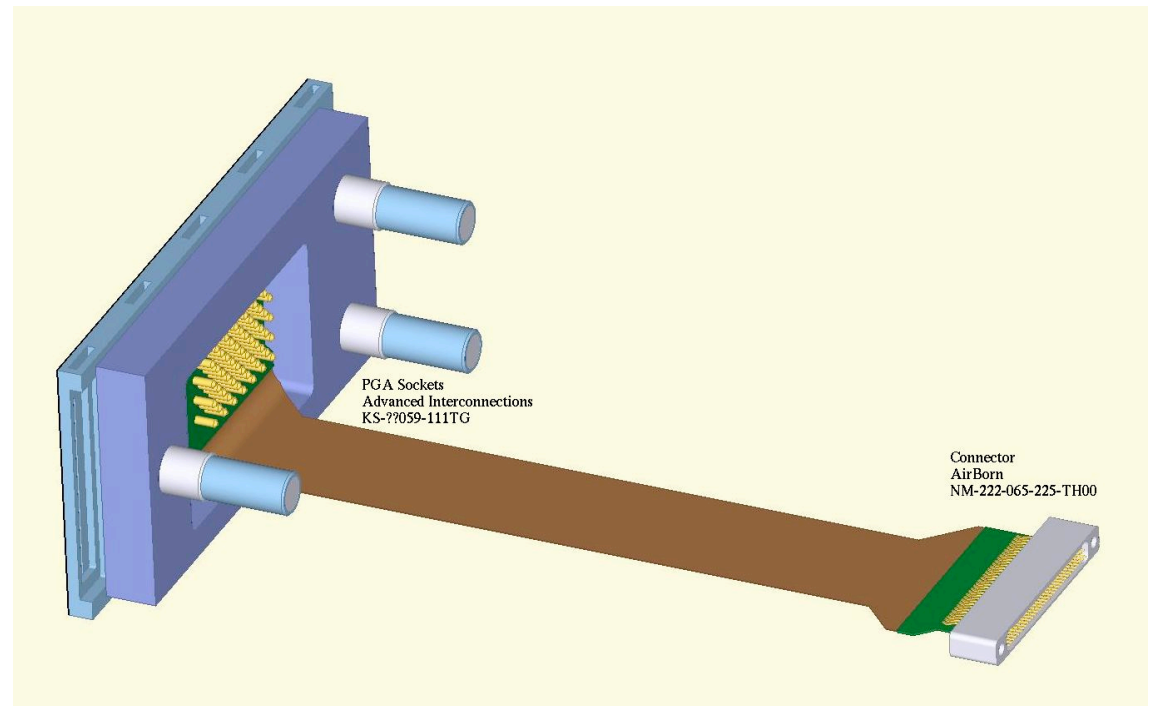
3 phases

2 phases or 4 phases

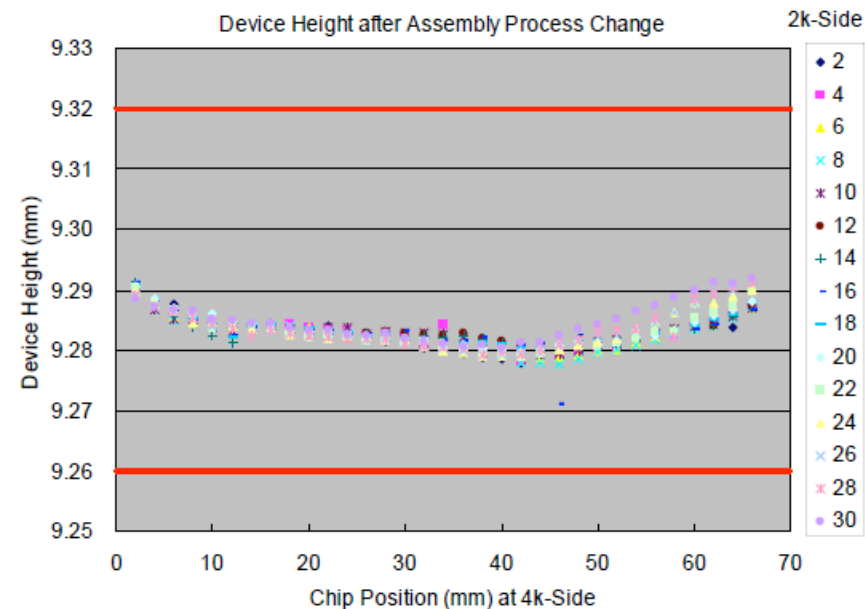
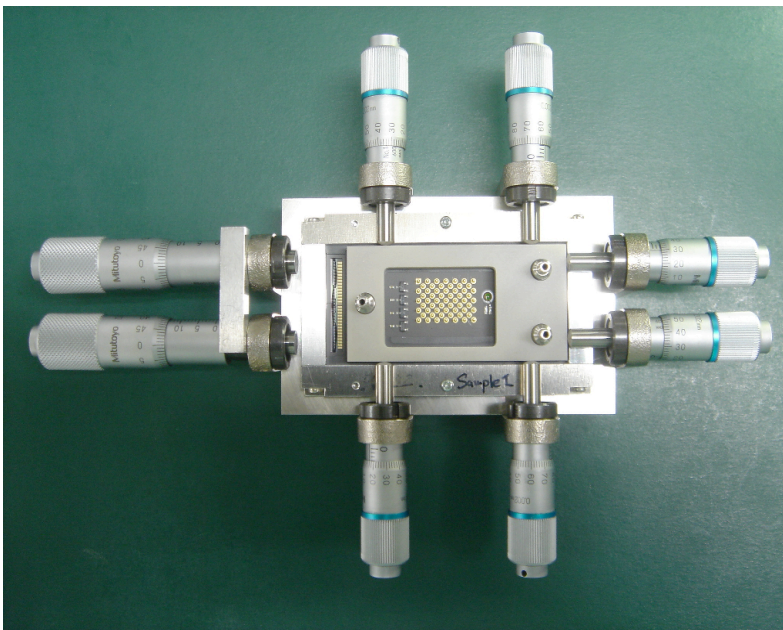
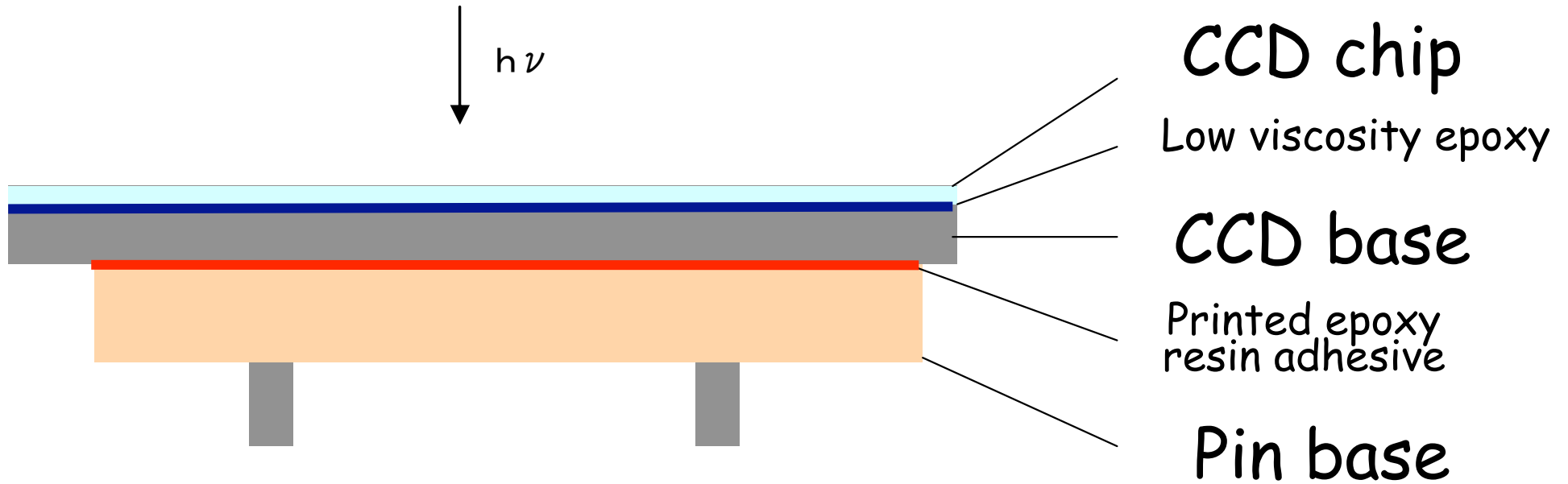
4 one stage MOSFET on chip
and one J-FET on the package

Package Material

Aluminum Nitride

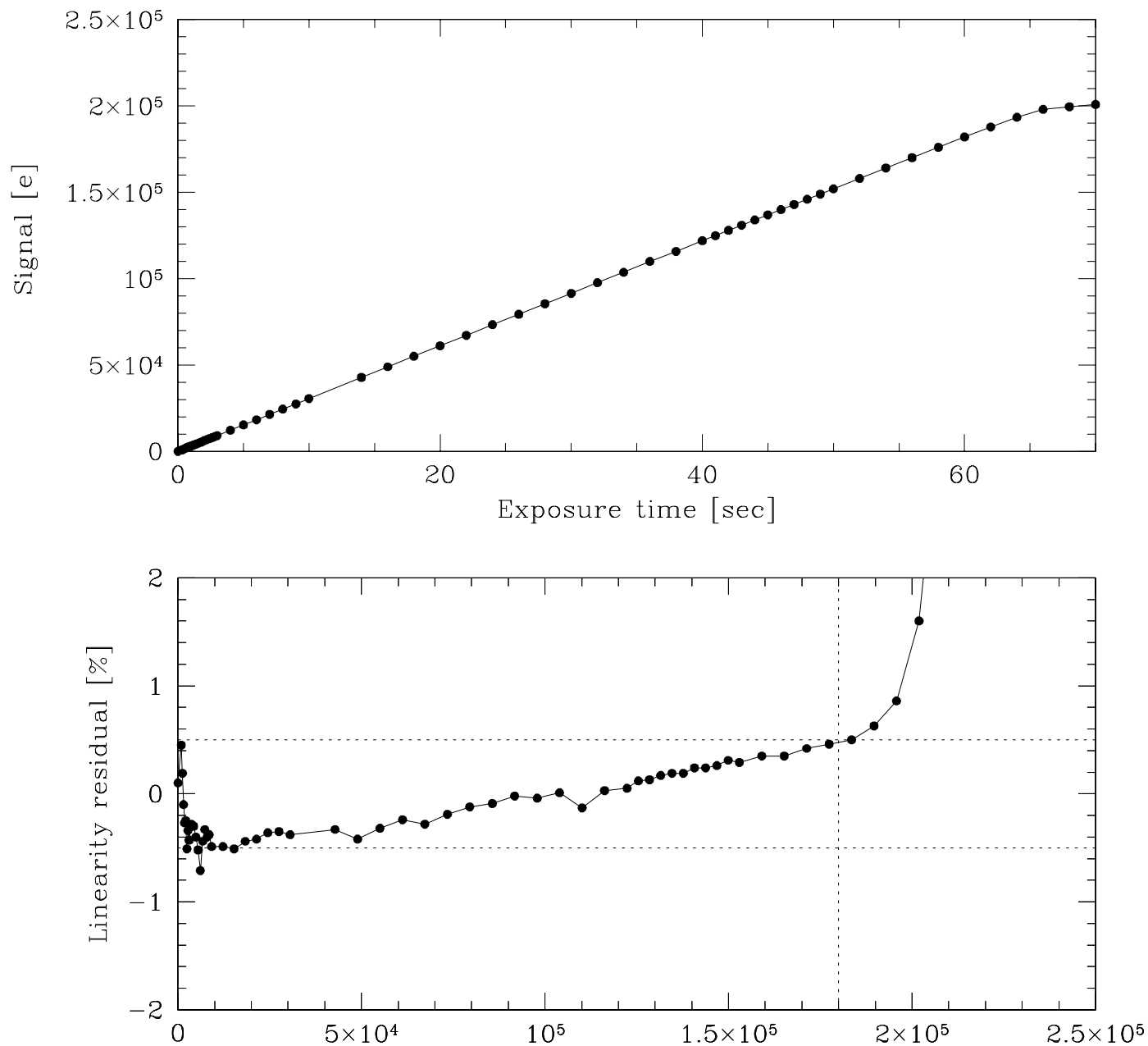


Package Structure



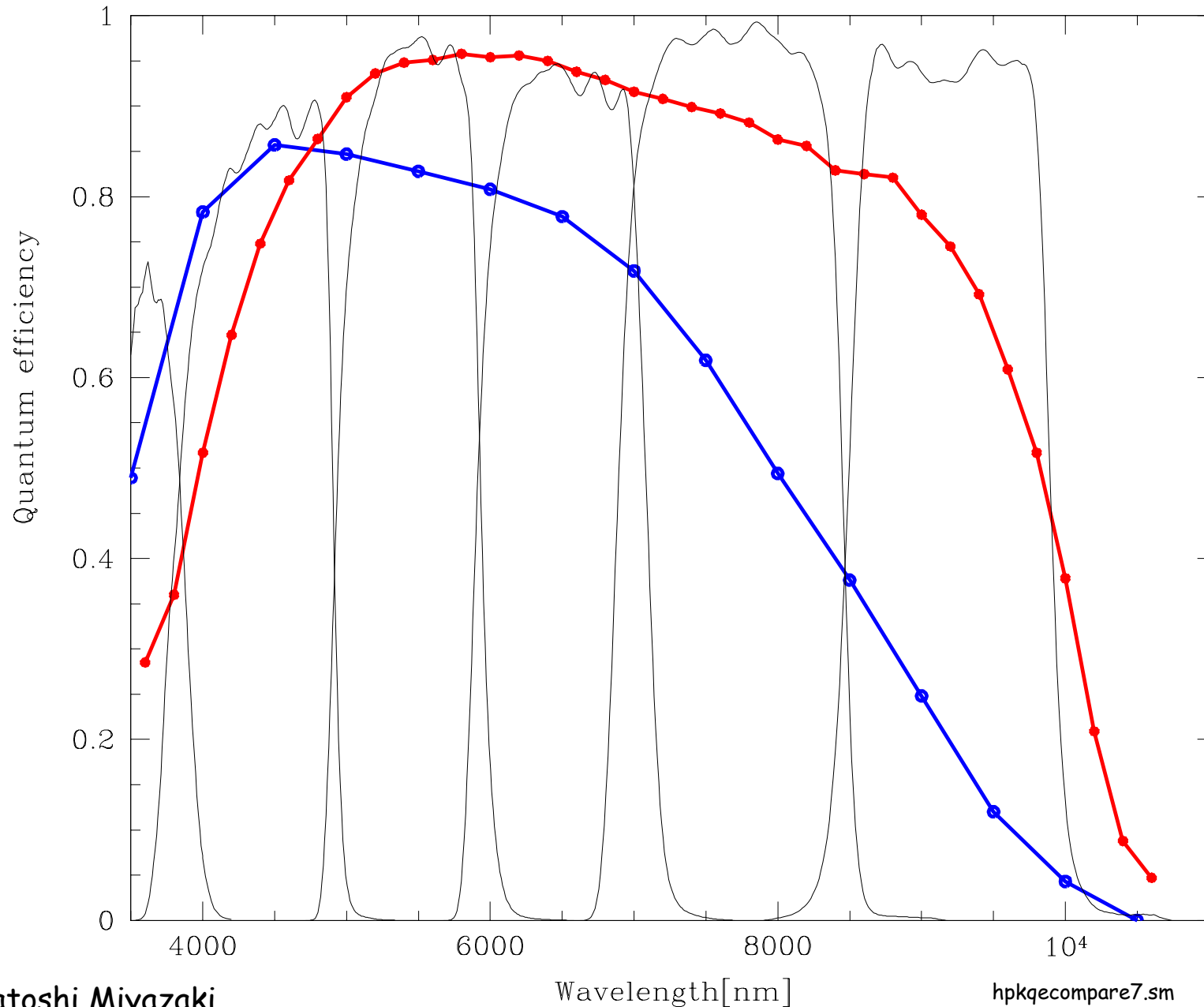
10um
flatness
achieved

Full well





Optical Quantum Efficiency



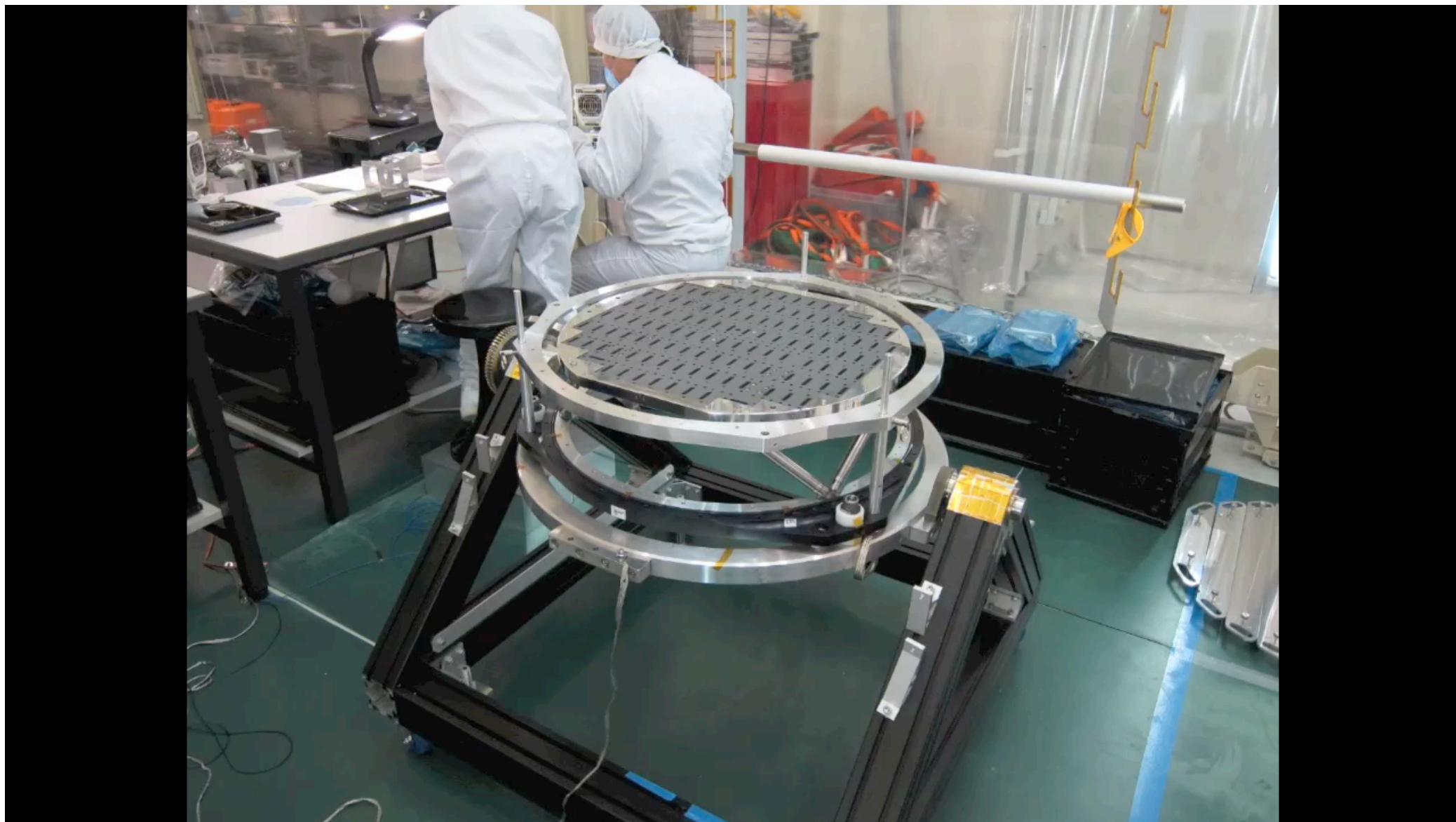
Hamamatsu
FDCCD

e2v CCD for
MegaCam



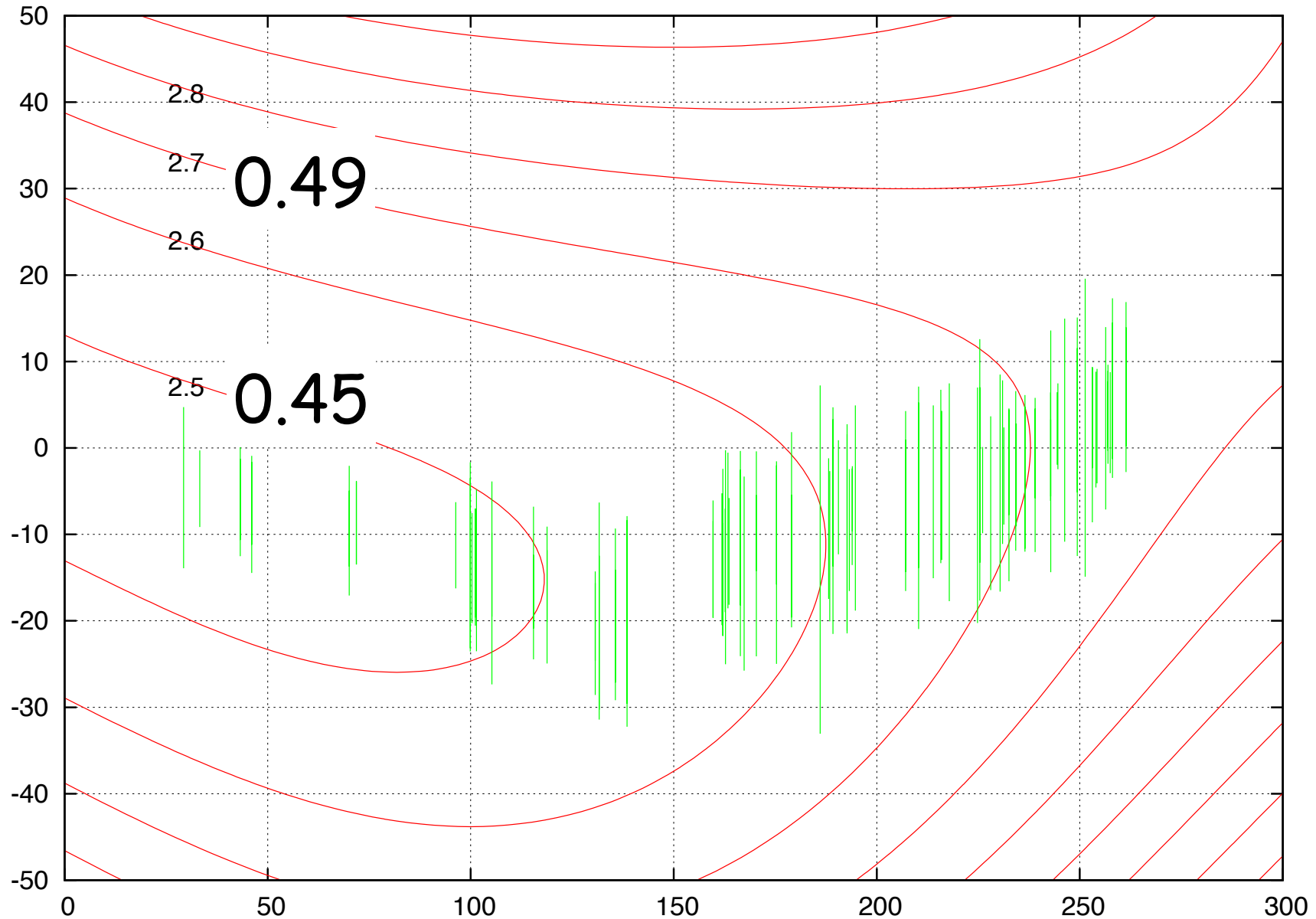
CCD Performance

Items		Requirement (-100°C)	Measured
Packaging	Format (pixel size)	2048×4096 (15 μm^2)	-
	Pixel to Package edge	< 0.5 mm	0.410±0.025
	(Serial register side)	< 5.0 mm	4.975±0.025
	Global height variation	< 25 μm Peak-to-Valley	
QE	400 nm	> 45	42
	550 nm	> 85	87
	650 nm	> 90	94
	770 nm	> 85	91
	920 nm	> 80	78
	1000 nm	> 40	40
CTE (per pix)	Parallel direction	> 0.999995 (1600 e)	0.999999
	Serial direction	> 0.999995 (1600 e)	0.999998
Dark Current		< a few e/hour/pix	1.4
Charge diffusion		$\sigma_D < 7.5 \mu\text{m}$ (400 < λ < 1050 nm)	7.5
Full well	1 % departure	> 150,000 e	180,000
Amp. Responsivity		> 4 $\mu\text{V}/\text{e}$	4.5
Readout noise	150 kHz readout	< 5 e	4.5





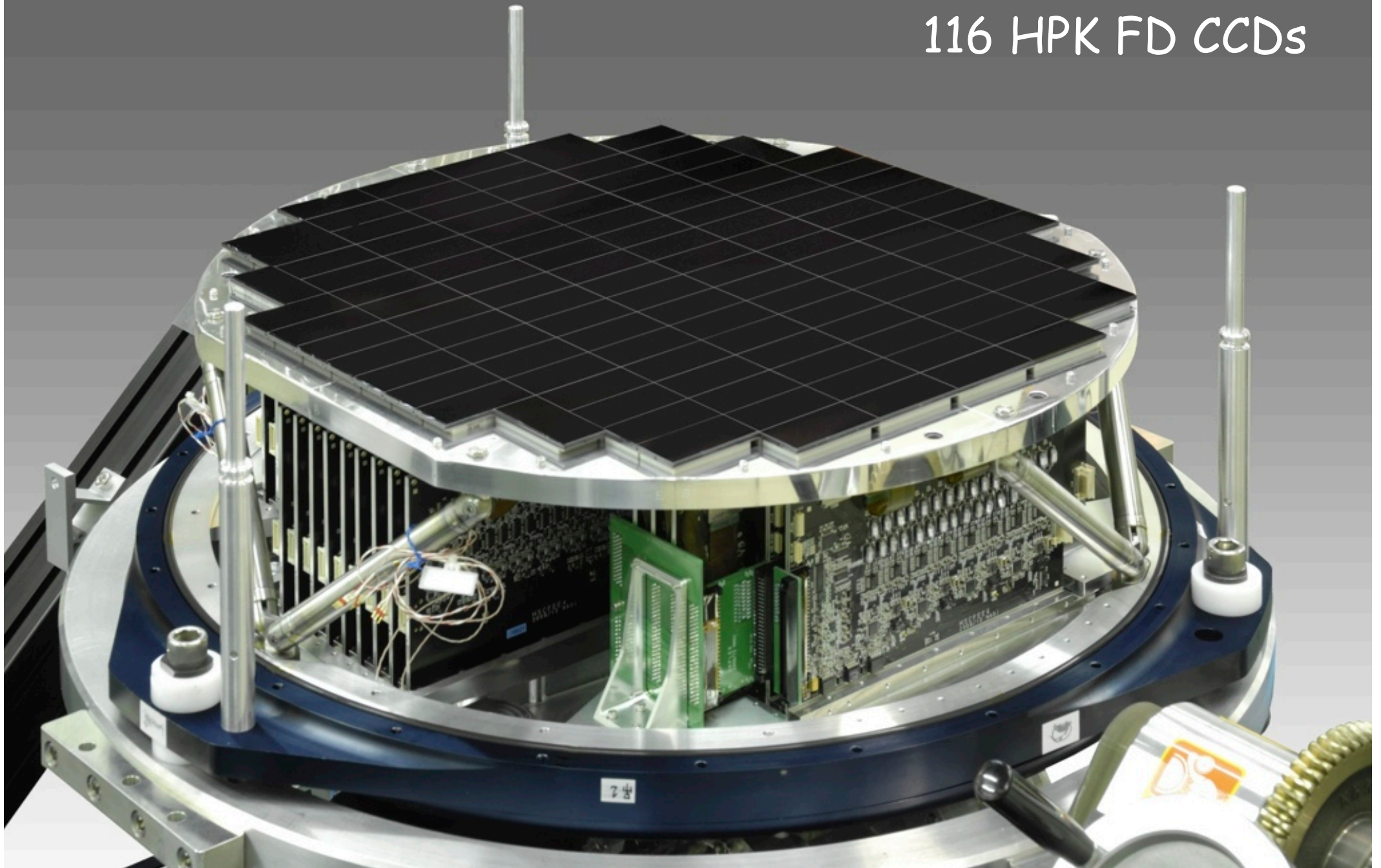
Flatness of the Focal Plane





HSC Focal Plane

116 HPK FD CCDs





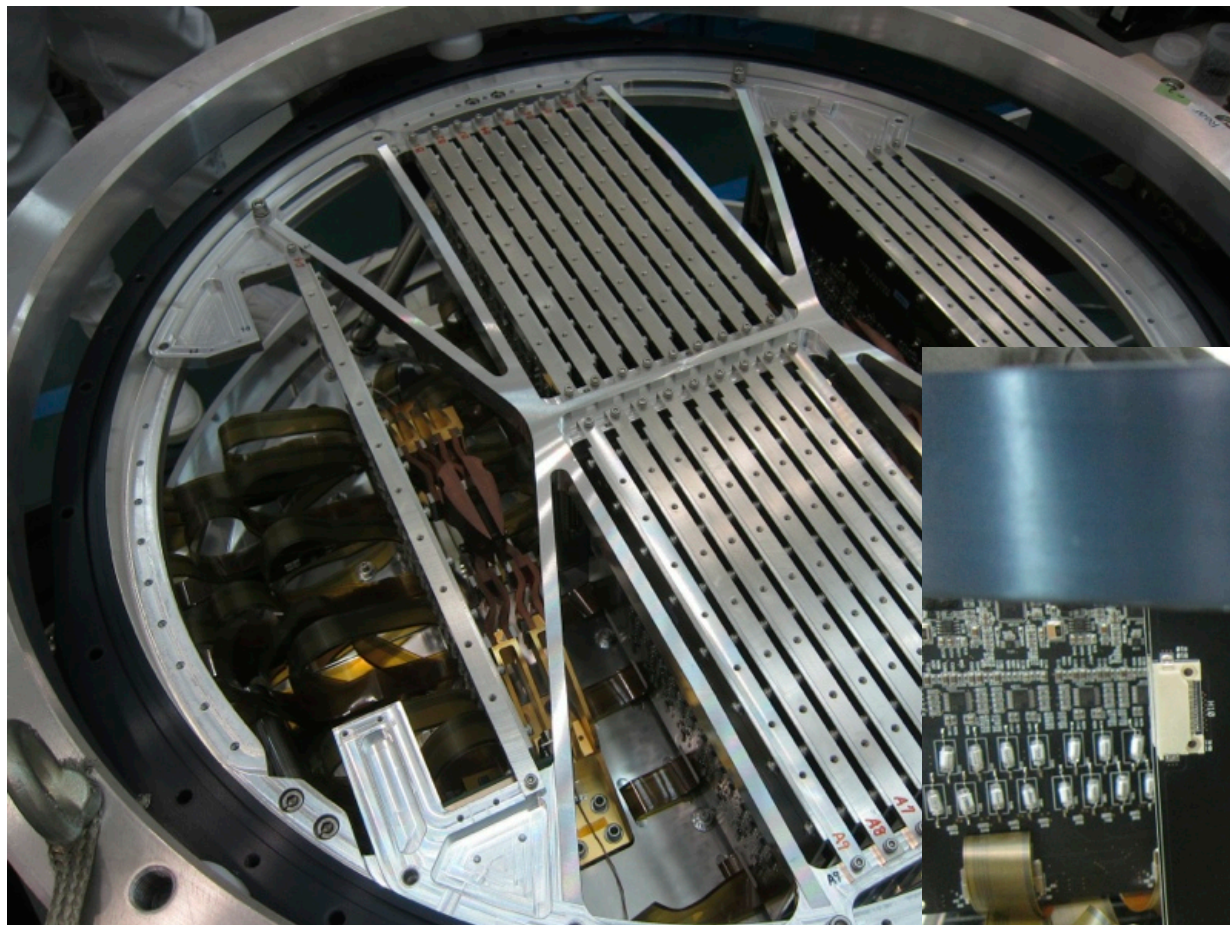
Assembly of the Dewar

$t=37\text{mm}$ Quartz Window $\sim 20\text{ kg}$

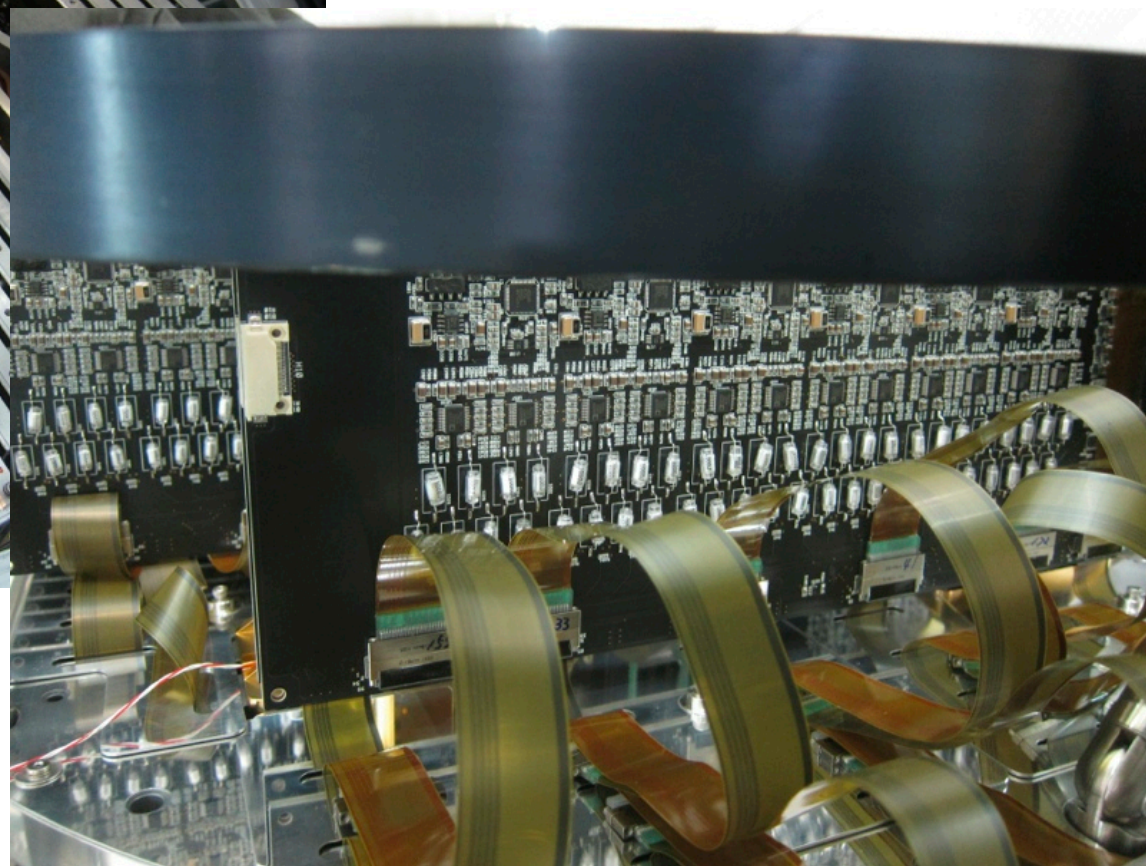




In-Dewar Electronics Assembly



150 kpix/s
R.N. ~ 4 e(inc. CCD)
 ~ 25 sec R.O. time



Nakaya et al. 8453-101

CCD Read Out

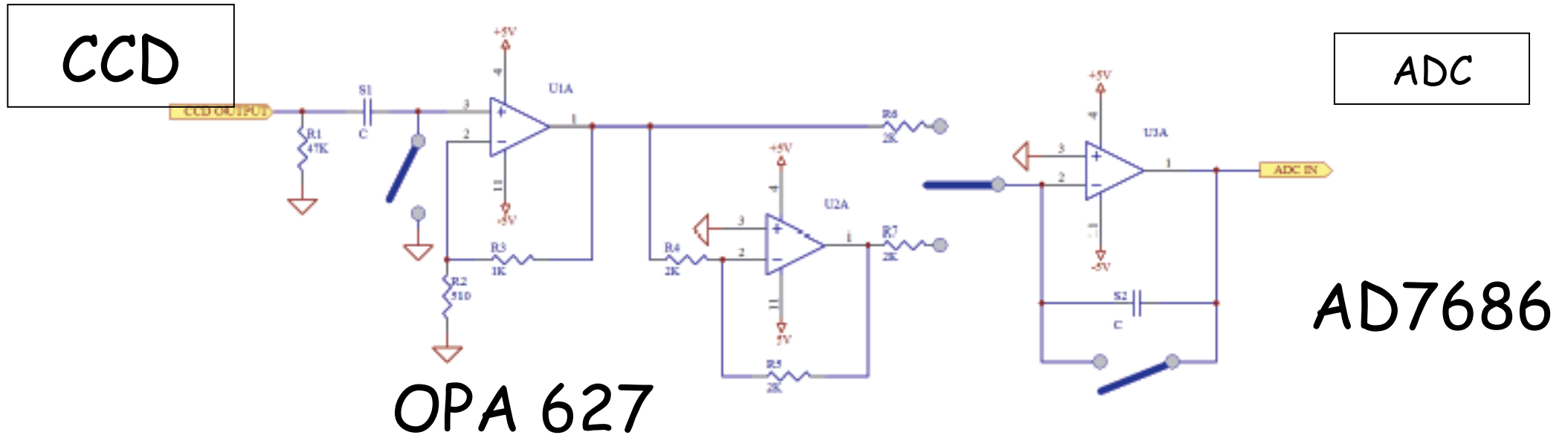


Figure 1.4: Pre-amplifier and CDS circuit

AC-couple

Single Non-inverting Amp

Integration Type
CDS

~ 150 kpix/sec =
15 sec readout



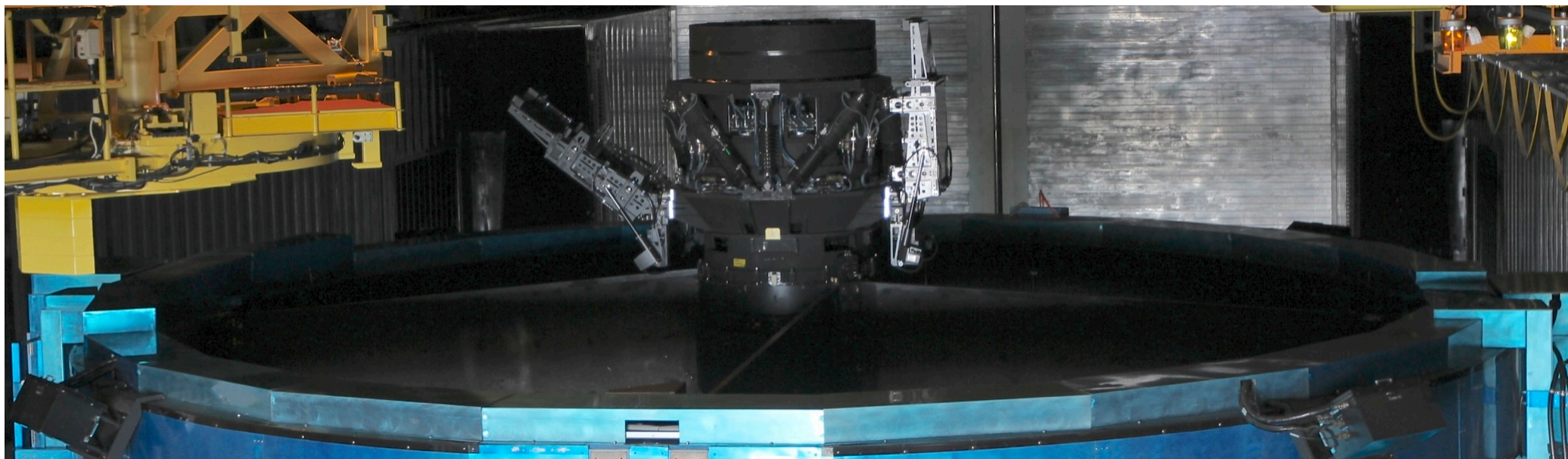
Camera Unit Assembly





Camera docking with POPT2

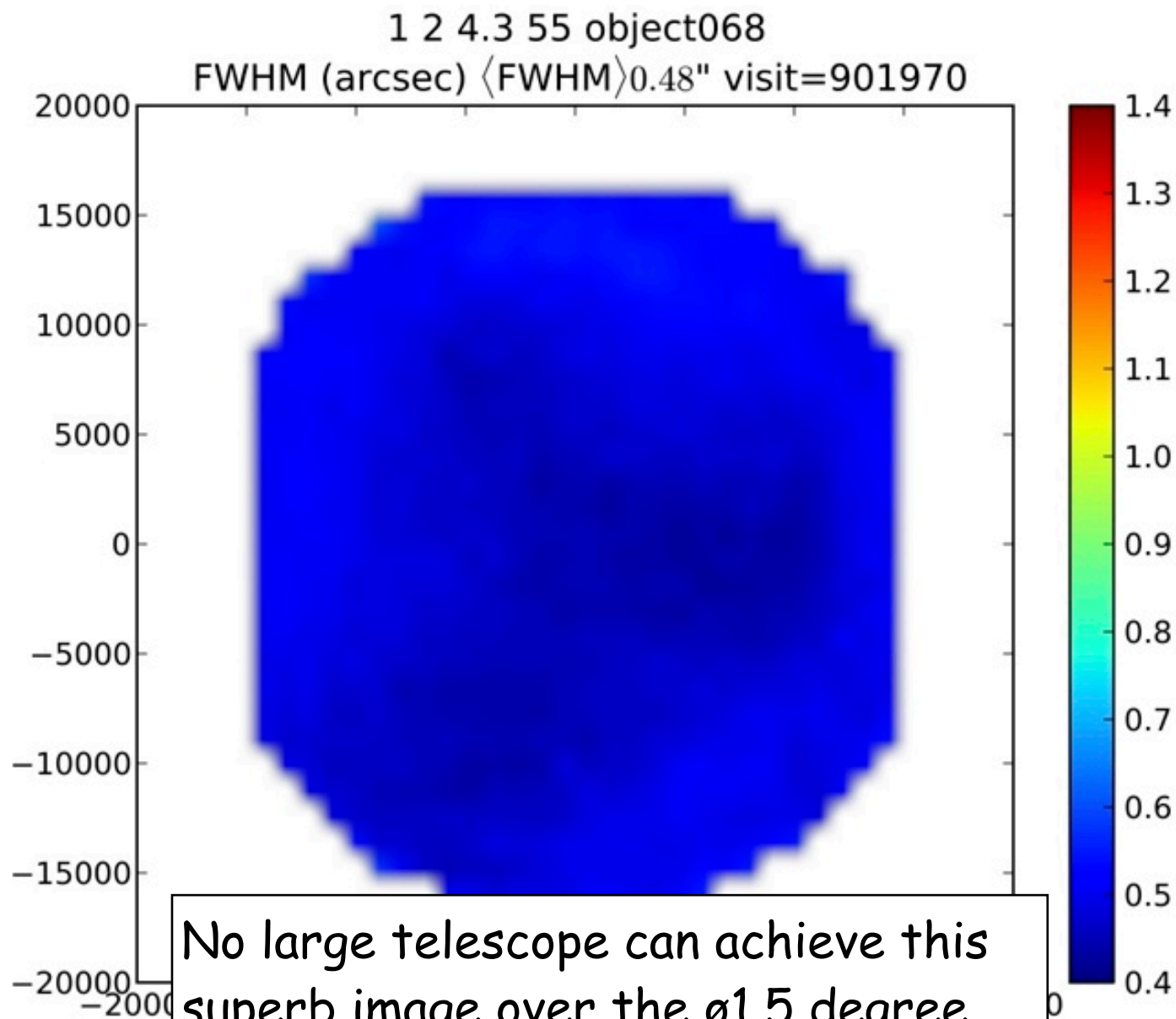
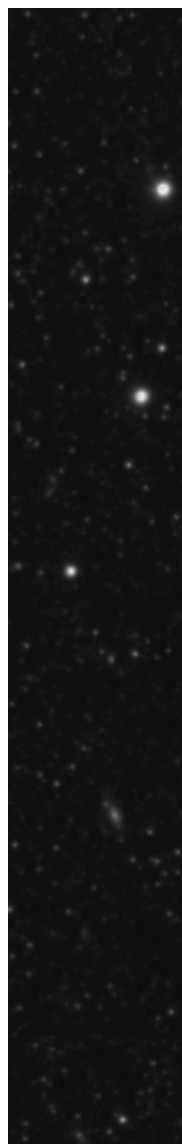




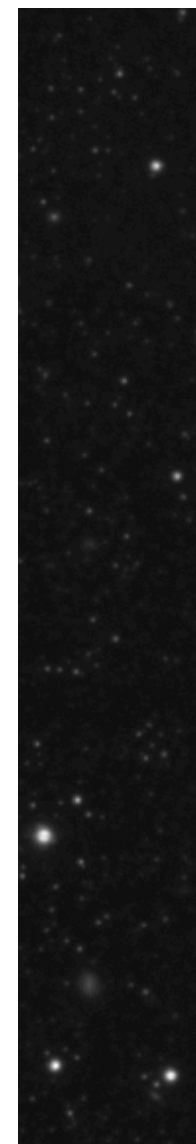
Filter Exchanger Ready and Installed



Performance Test using Stars

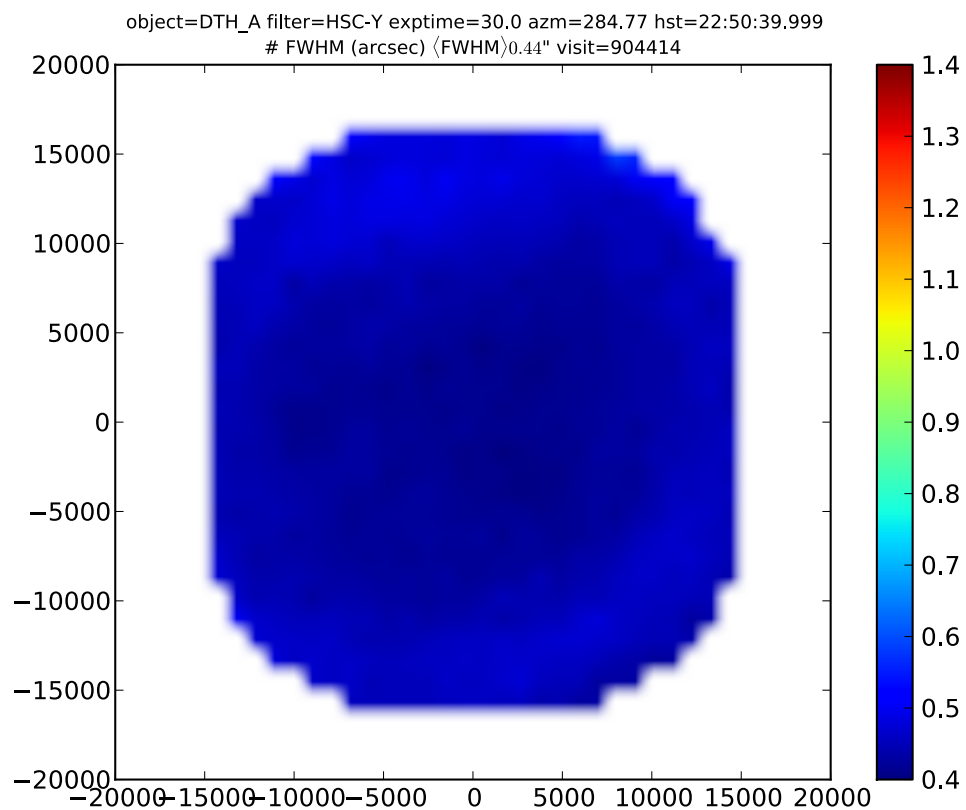


No large telescope can achieve this superb image over the $\phi 1.5$ degree field of view.



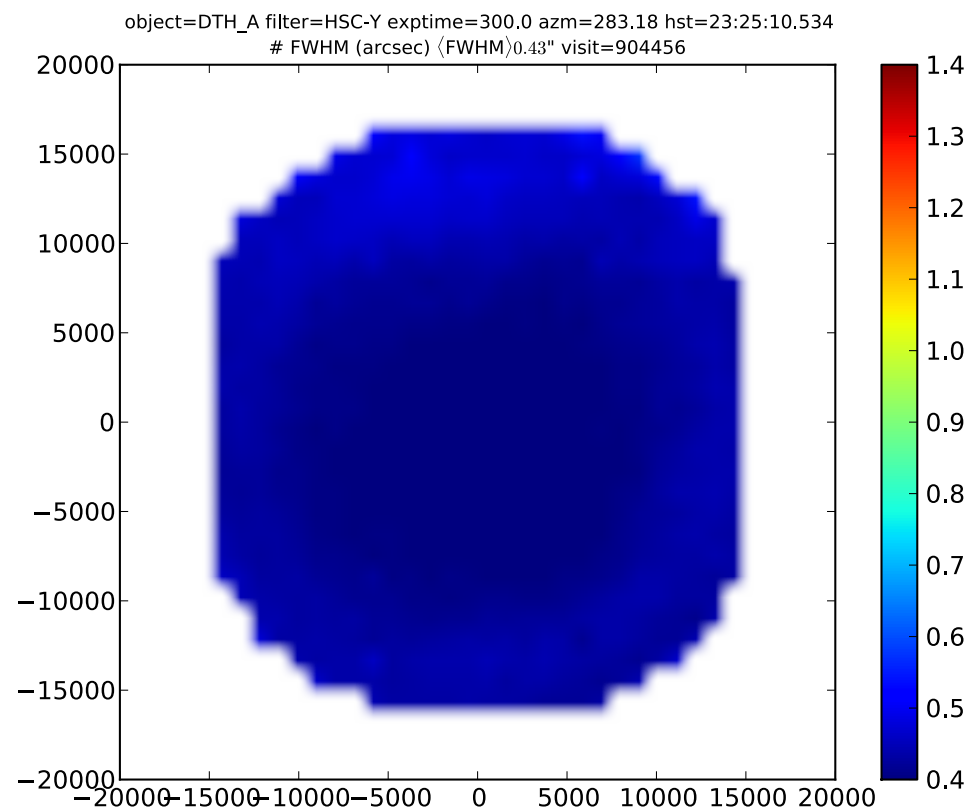


HSC Best Seeing Record



←→ 1.5 deg

Nov. 2 2013 22:49
object059
EL=70
Texp = 30
 $\langle \text{FWHM} \rangle \sim 0''.42$
Y-band



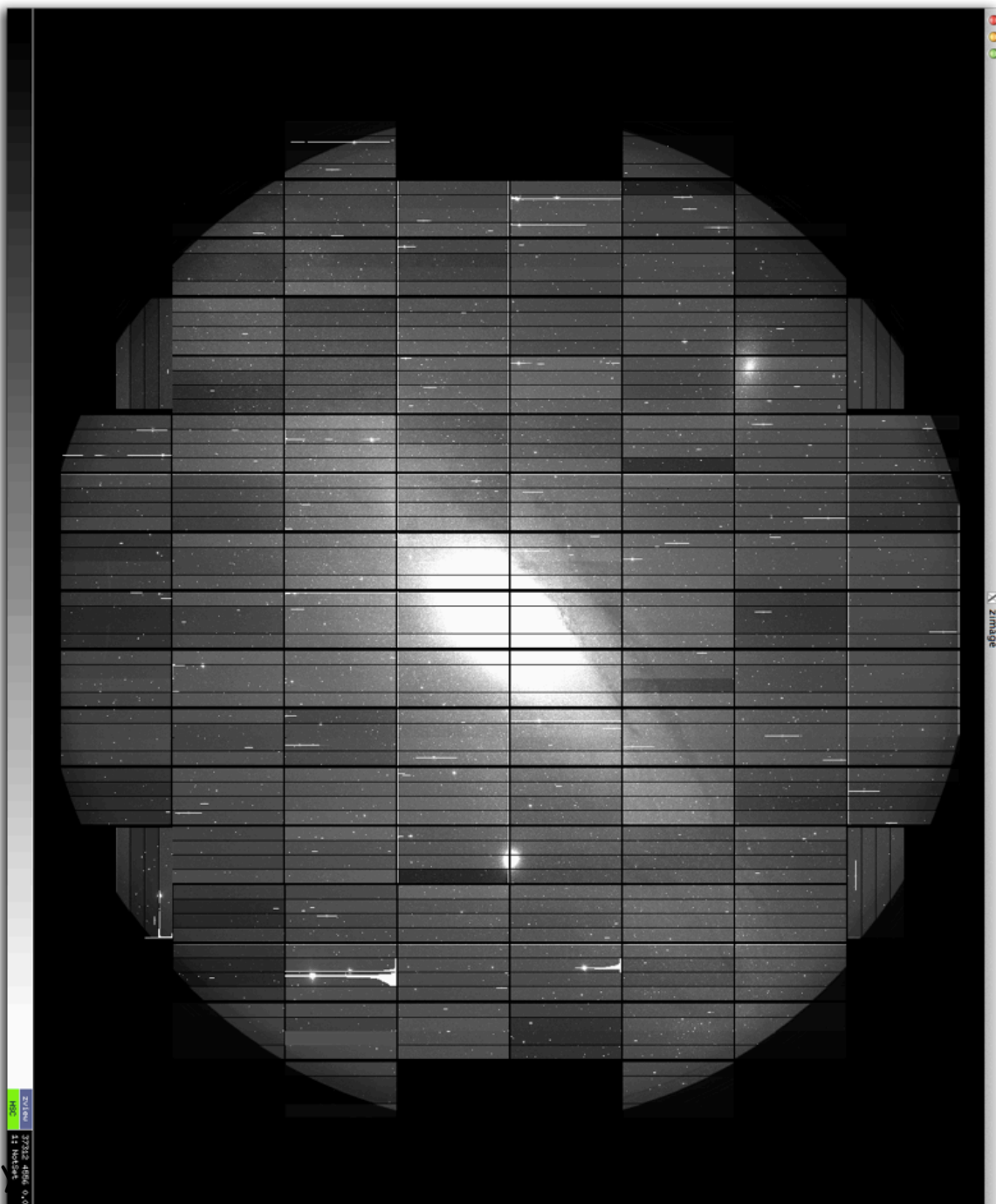
Nov. 2 2013 23:25
object081
EL=62
Texp = 300 (no guide)
 $\langle \text{FWHM} \rangle \sim 0''.43$
Y-band



Performance Check Using Stars

- No degradation of the image quality observed when we lower the elevation down to 25 deg
- Misalignment due to flexure minimum as designed
- System throughput evaluated using SDSS stars and consistent with the expectation within 5 %

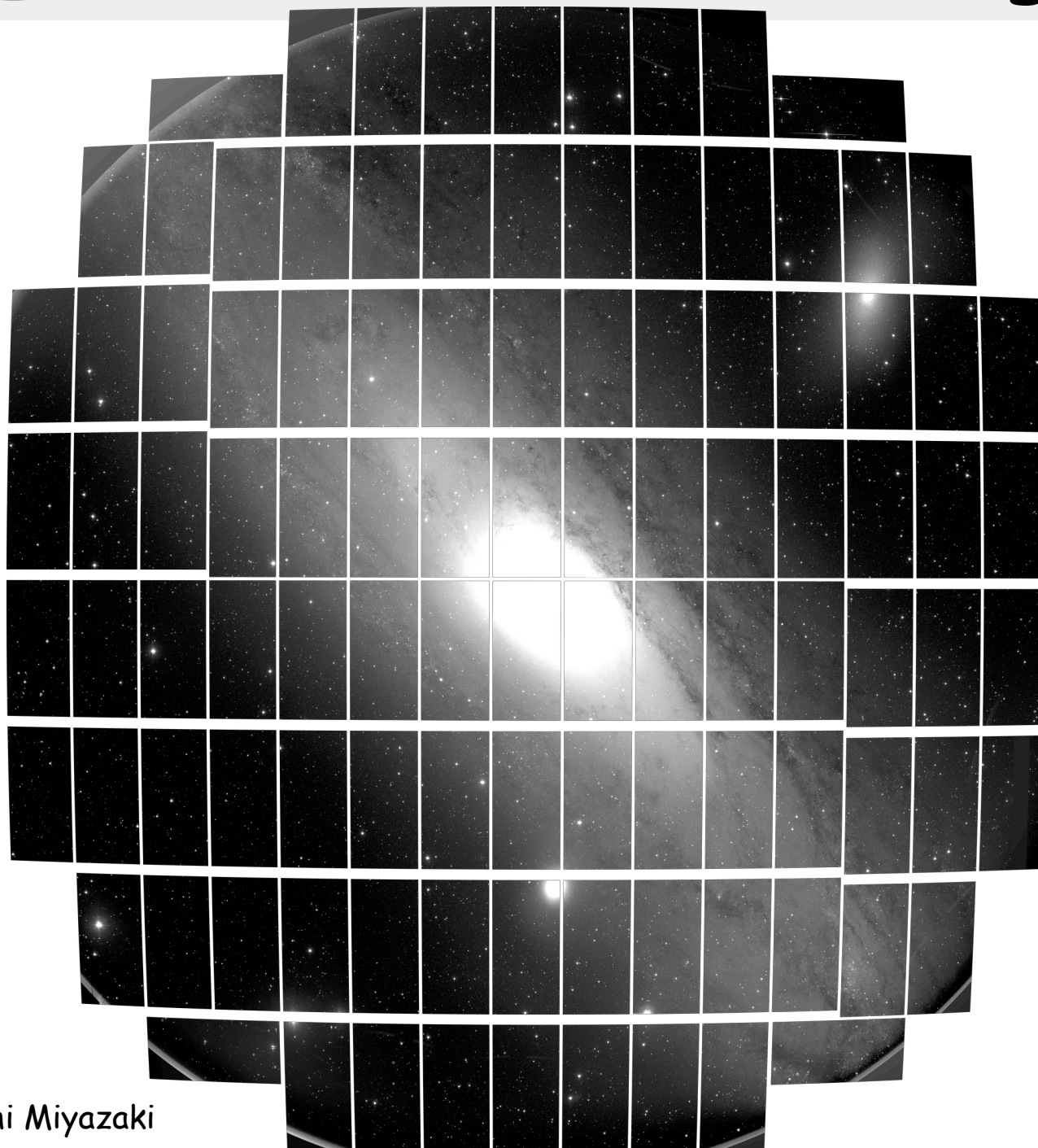
Image of M31



CCD read out and
save onto the
disk in ~ 25 sec



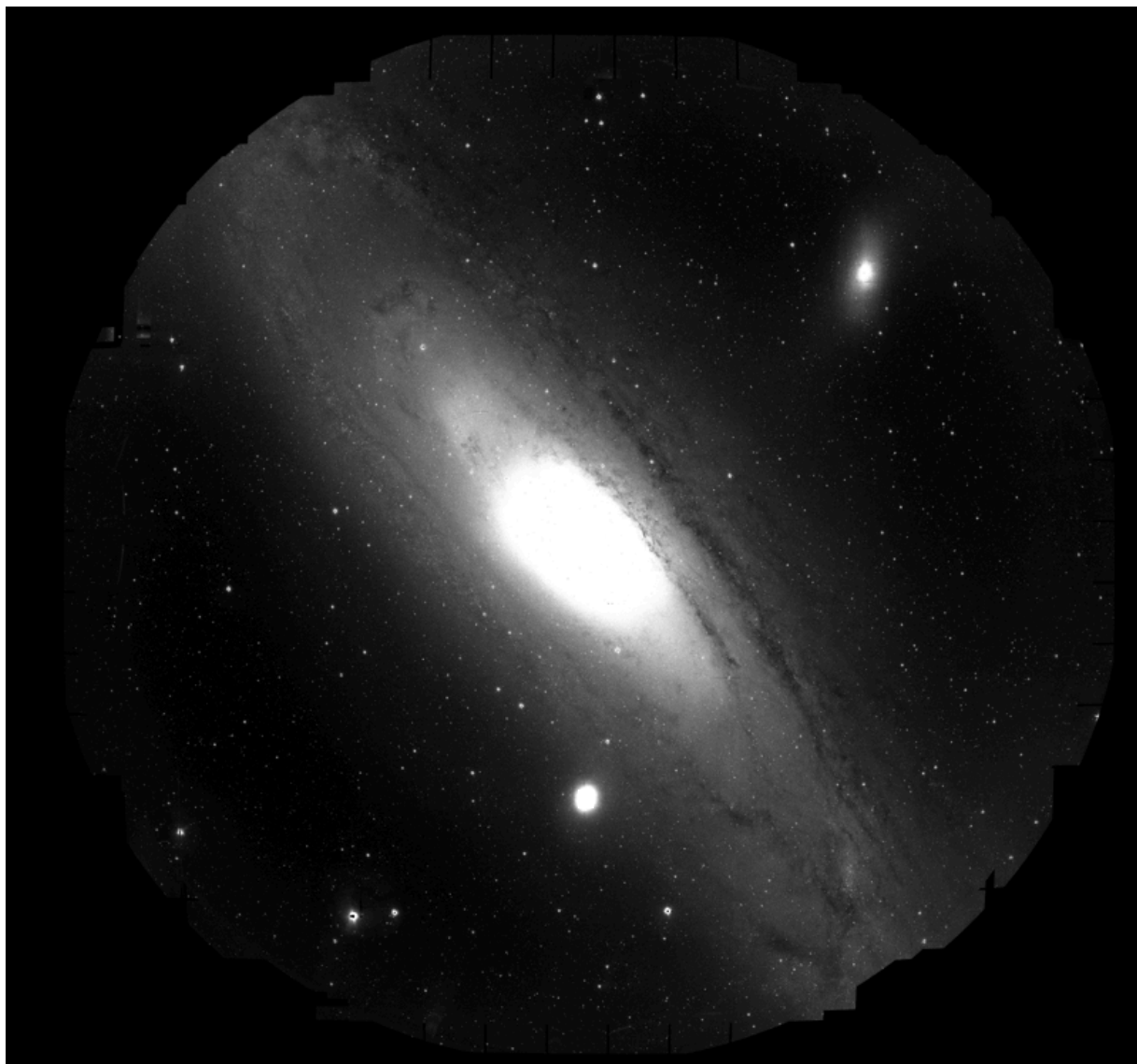
HSC M31 Image



Bias Subtraction
Flat Fielding

Warp CCD images
to map onto the
sky

Image of M31



5 dithered
exposures (2.8 min
each av.) to filled
the gaps of CCDs

1400/10000 will be replaced with the deeper
HSC images on google sky



Observing Proposal

- 300 nights
- 166 Collaborators
- 2012/10 Submitted

Wide-field imaging with Hyper Suprime-Cam:
Cosmology and Galaxy Evolution
A Strategic Survey Proposal for the Subaru Telescope

PI: Satoshi Miyazaki (NAOJ)
Co-PI: Ikuru Iwata (NAOJ)

The HSC collaboration team¹: S. Abe⁽¹⁾, H. Aihara^{*(2),(3)}, M. Akiyama⁽⁴⁾, K. Aoki⁽⁵⁾, N. Arimoto^{*(5)}, N. A. Bahcall⁽⁶⁾, S. J. Bickerton⁽³⁾, J. Bosch⁽⁶⁾, K. Bundy^{†(3)}, C. W. Chen⁽⁷⁾, M. Chiba^{†(4)}, T. Chiba⁽⁸⁾, N. E. Chisari⁽⁶⁾, J. Coupon⁽⁷⁾, M. Doi⁽²⁾, M. Enoki⁽⁹⁾, S. Foucaud⁽¹⁰⁾, M. Fukugita⁽³⁾, H. Furusawa^{†(5)}, T. Futamase⁽⁴⁾, R. Goto⁽²⁾, T. Goto⁽¹¹⁾, J. E. Greene⁽⁶⁾, J. E. Gunn^{†(6)}, T. Hamana^{†(5)}, T. Hashimoto⁽²⁾, M. Hayashi⁽⁵⁾, Y. Higuchi^{(2),(5)}, C. Hikage⁽¹²⁾, J. C. Hill⁽⁶⁾, P. T. P. Ho^{*(7)}, B. C. Hsieh⁽⁷⁾, K. Y. Huang^{†(7)}, H. Ikeda⁽¹³⁾, M. Imanishi⁽⁵⁾, N. Inada⁽¹⁴⁾, A. K. Inoue⁽¹⁵⁾, W.-H. Ip⁽¹⁾, T. Ito⁽⁵⁾, K. Iwasawa⁽¹⁶⁾, M. Iye⁽⁵⁾, H. Y. Jian⁽¹⁷⁾, Y. Kakazu⁽¹⁸⁾, H. Karoji⁽³⁾, N. Kashikawa⁽⁵⁾, N. Katayama⁽³⁾, T. Kawaguchi⁽¹⁹⁾, S. Kawanomoto⁽⁵⁾, I. Kayo⁽²⁰⁾, T. Kitayama⁽²⁰⁾, G. R. Knapp⁽⁶⁾, T. Kodama⁽⁵⁾, K. Kohno⁽²⁾, M. Koike⁽⁵⁾, E. Kokubo⁽⁵⁾, M. Kokubo⁽²⁾, Y. Komiyama⁽⁵⁾, A. Konno⁽²⁾, Y. Koyama⁽⁵⁾, C. N. Lackner⁽³⁾, D. Lang⁽⁶⁾, A. Leauthaud^{†(3)}, M. J. Lehner⁽⁷⁾, K.-Y. Lin⁽⁷⁾, I. Lin⁽⁷⁾, Y.-T. Lin^{†(7)}, C. P. Loomis⁽⁶⁾, R. H. Lupton^{†(6)}, P. S. Lykawka⁽²¹⁾, K. Maeda⁽³⁾, R. Mandelbaum^{†(22)}, Y. Matsuoka^{(13),(23)}, Y. Matsuoka⁽¹²⁾, S. Mineo⁽²⁾, T. Minezaki⁽²⁾, H. Miyatake⁽⁶⁾, R. Momose⁽²⁾, A. More⁽³⁾, S. Morokuma^{†(2)}, H. Murayama^{*(3)}, K. Nagamine⁽²⁴⁾, T. Nagao^{†(23)}, S. Nagataki⁽²³⁾, Y. Naito⁽²⁾, K. Nakata⁽⁵⁾, H. Nakaya⁽⁵⁾, T. Namikawa⁽²⁾, C.-C. Ngeow⁽¹⁾, T. Nishimichi⁽³⁾, H. Nishioka⁽⁷⁾, A. J. Nishizawa^{†(3)}, M. Oguri^{†(3)}, A. Oka⁽²⁾, N. Okabe⁽⁷⁾, S. Okamoto⁽²⁵⁾, S. Okamura⁽²⁶⁾, J. Okumura⁽²³⁾, S. Okumura⁽²⁷⁾, Y. M. Onodera⁽²⁸⁾, K. Ota⁽²³⁾, M. Ouchi^{†(2)}, S. Oyabu⁽¹²⁾, P. A. Price⁽⁶⁾, R. Quimby⁽³⁾, C. E. Rusu^{(2),(5)}, S. Y. Saitou⁽³⁰⁾, M. Sato⁽¹²⁾, T. Shibuya⁽⁵⁾, K. Shimasaku^{†(2)}, A. Shimono⁽³⁾, S. Shinogi⁽²⁾, M. Shirasaki⁽²⁾, N. Spergel^{*(6),(3)}, M. A. Strauss^{†(6)}, H. Sugai⁽³⁾, N. Sugiyama^{(12),(3)}, D. Suto⁽²⁾, Y. Suto^{*(2)}, K. Tadaki⁽²⁾, S. Takahashi⁽³¹⁾, S. Takahashi⁽⁵⁾, T. Takata⁽⁵⁾, T. T. Takeuchi⁽¹²⁾, N. Tamura⁽³⁾, M. Tanaka⁽⁵⁾, M. Tanaka^{†(3)}, Y. Higuchi⁽¹³⁾, A. Taruya⁽²⁾, T. Terai⁽⁵⁾, Y. Terashima⁽¹³⁾, N. Tominaga⁽³²⁾, J. Toshikawa⁽³⁰⁾, T. Totani⁽²³⁾, Y. Ueda⁽²³⁾, K. Umetsu⁽⁷⁾, Y. Urata^{†(1)}, Y. Utsumi⁽⁵⁾, B. Vulcani⁽³⁾, K. Wada⁽³³⁾, S.-Y. Wang⁽⁷⁾, Y. Yamada⁽⁴⁾, Y. Yamada⁽⁵⁾, K. Yamamoto⁽³⁴⁾, H. Yamanoi⁽⁵⁾, C.-H. Yan⁽⁷⁾, N. Yasuda^{†(3)}, A. Yonehara⁽³⁵⁾, M. Yoshikawa⁽³⁶⁾, S. Yuma⁽²⁾

(1) NCU, Taiwan (2) Tokyo (3) Kavli IPMU (4) Tohoku (5) NAOJ (6) IAA (8) Nihon (9) Tokyo Keizai (10) NTNU, Taiwan (11) DARK, Copenhagen (12) Nagoya (13) Ehime (14) Osaka Sangyo (16) Barcelona (17) NTU, Taiwan (18) Chicago (19) Tsukuba (20) Toho (21) Kinki (22) CMU (23) Kyoto (24) Las Vegas (25) KIAA, China (26) Hosei (27) JSGA (28) ETH (29) Berkeley (30) GUAS (31) Hiroasaki (32) Konan (33) Kagoshima (34) Hiroshima (35) Kyoto Sangyo (36) JAXA

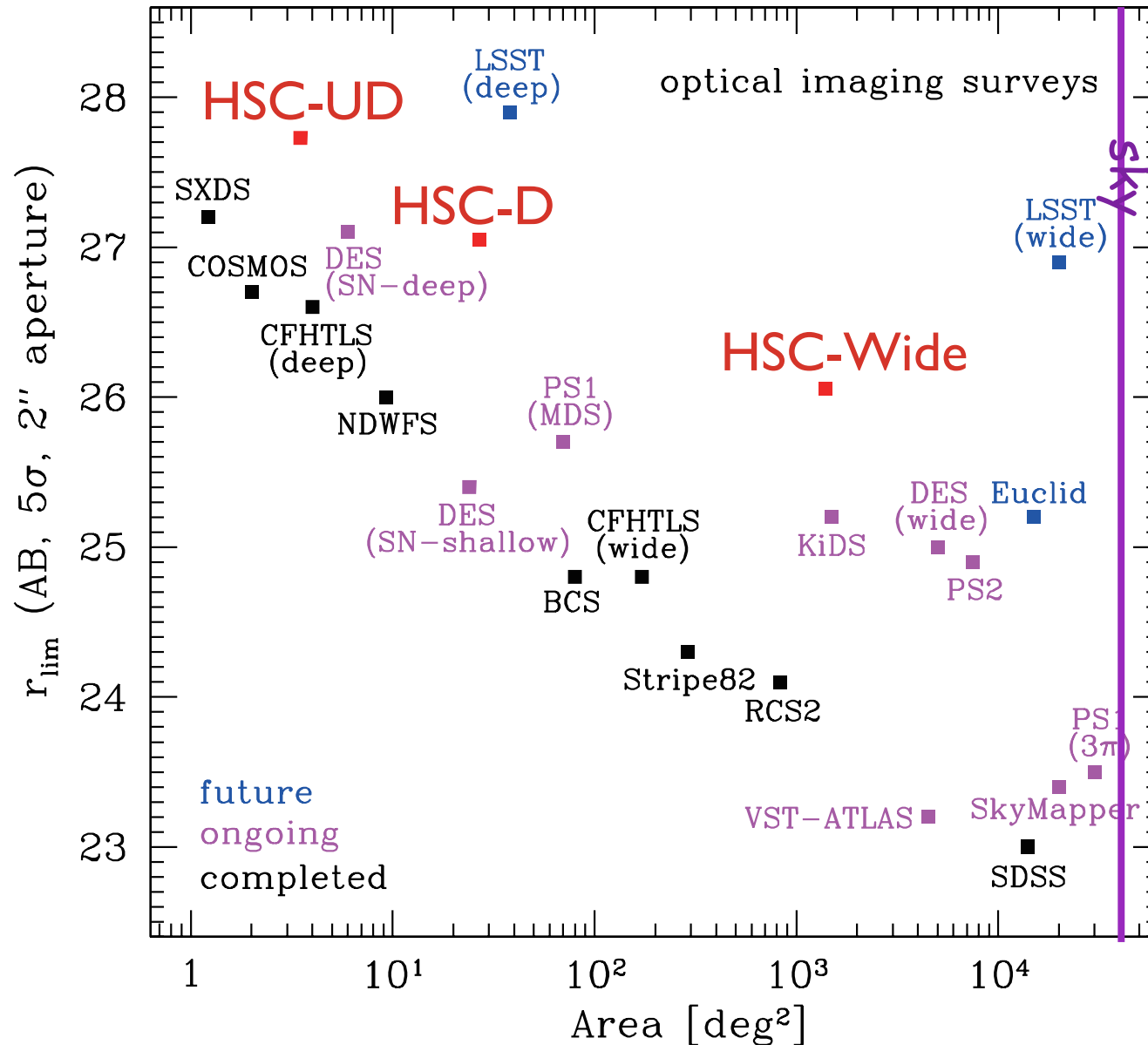
2013/05 Accepted

300 nights guaranteed
from 2014/02

2016:Mid term review



HSC SSP Survey: Three layers



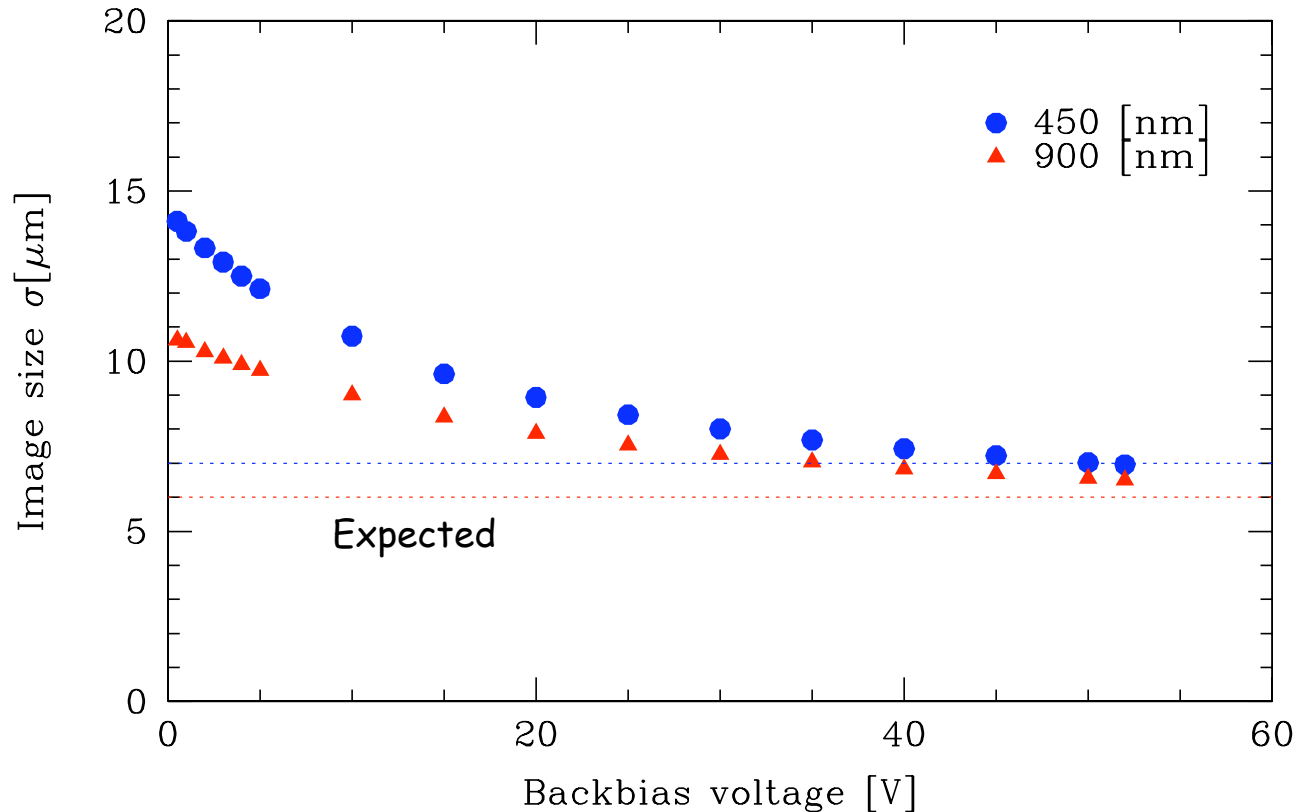
all sky

- Three-tier survey
 - Wide: 1400 sq. degs, $i \sim 26$
 - Deep: 28 sq. degs, $i \sim 27$
 - Ultradeep: 3 sq. degs, $i \sim 27.7$

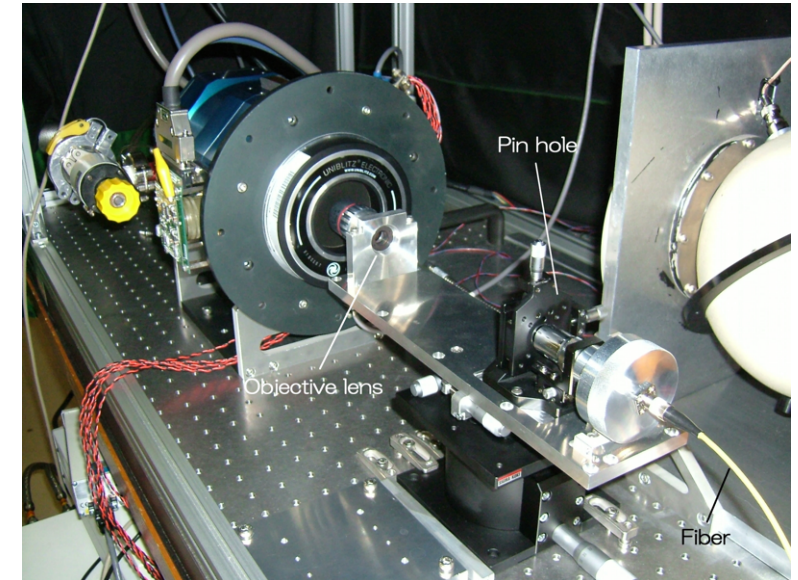
Fat PSF ?

- Can be a show-stopper ?
 - Shape measurement error ?
 - Crucial Error PSF photometry ?

Old setup of the measurement



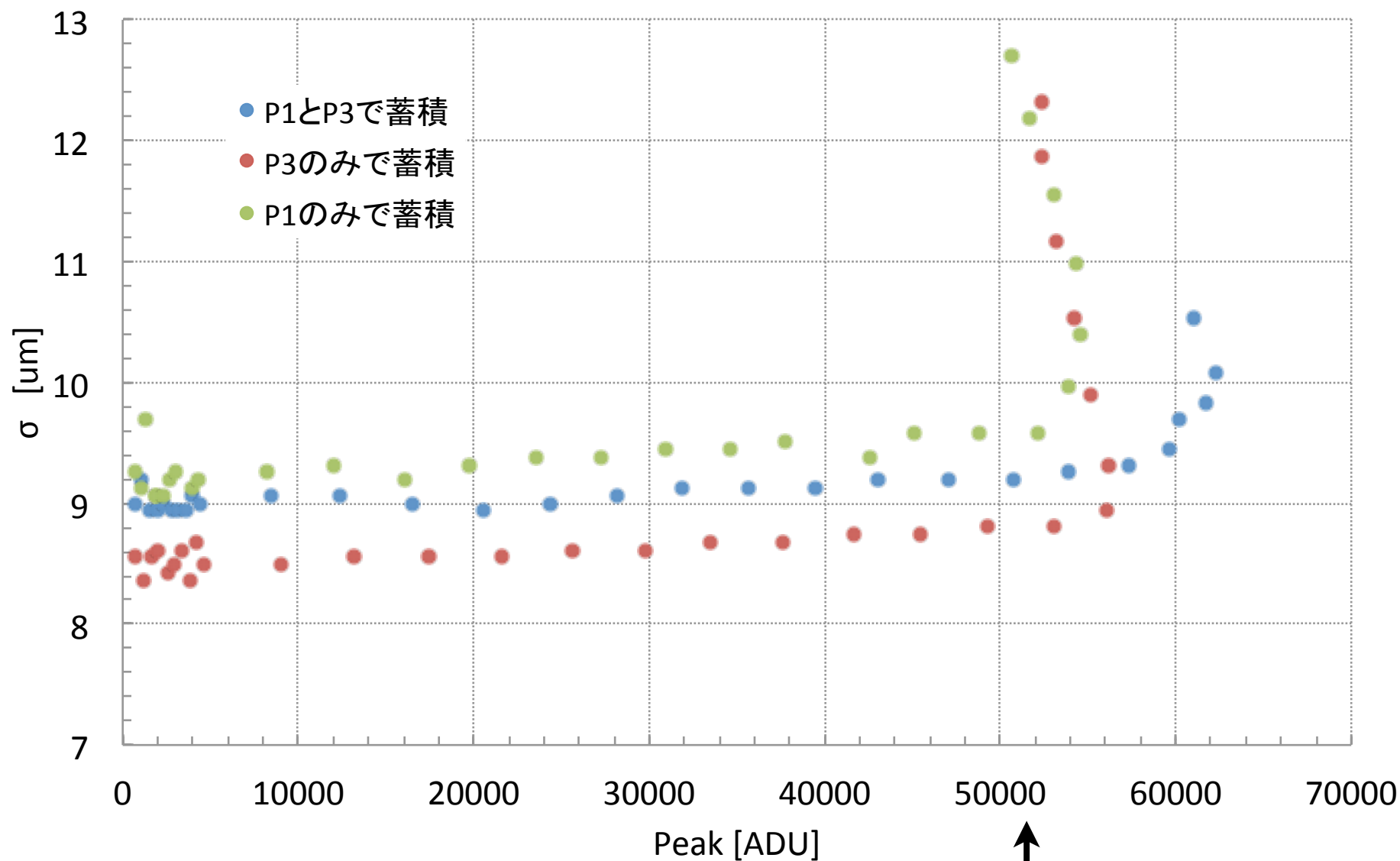
Measurement setup



10 micron pin hole is projected with X 1/10 (NA ~ 0.25) optics

Measurement is consistent with expected value.

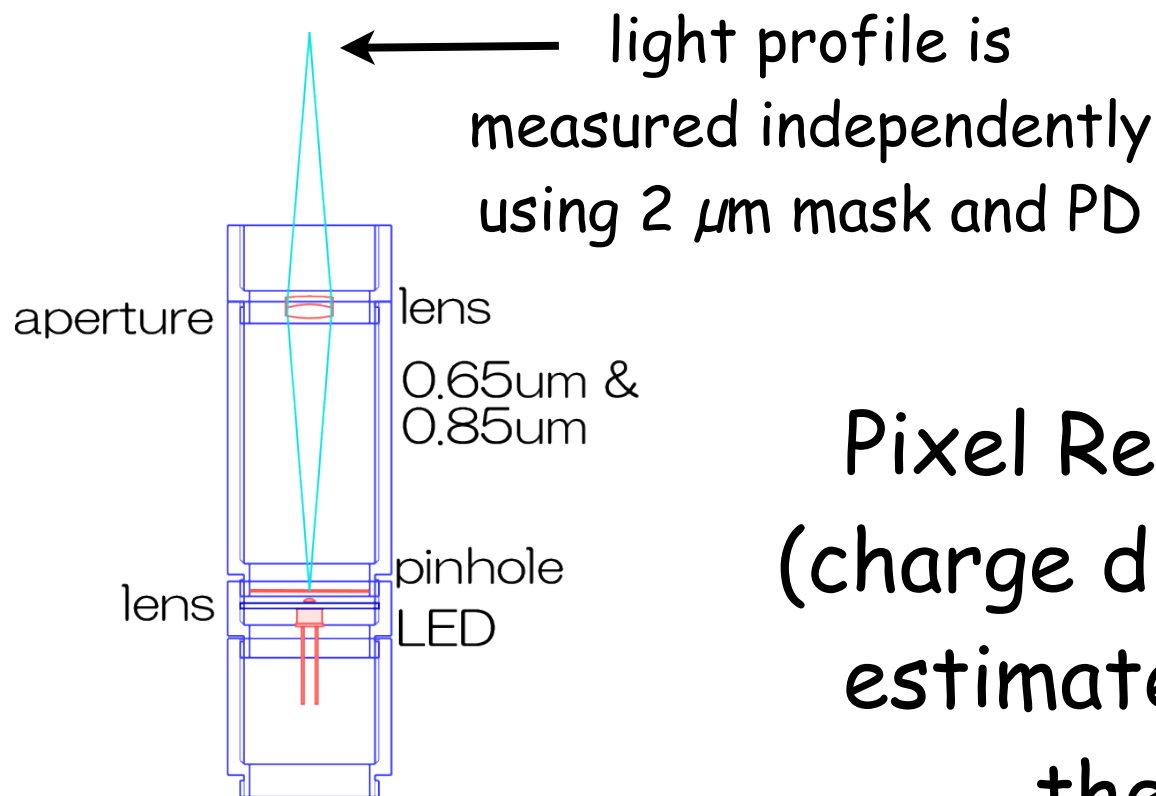
fat psf



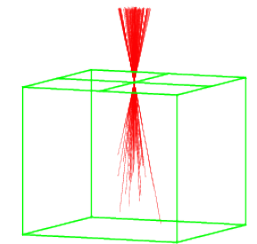
$$C.F. = 3e/ADU$$

↑
Full Well

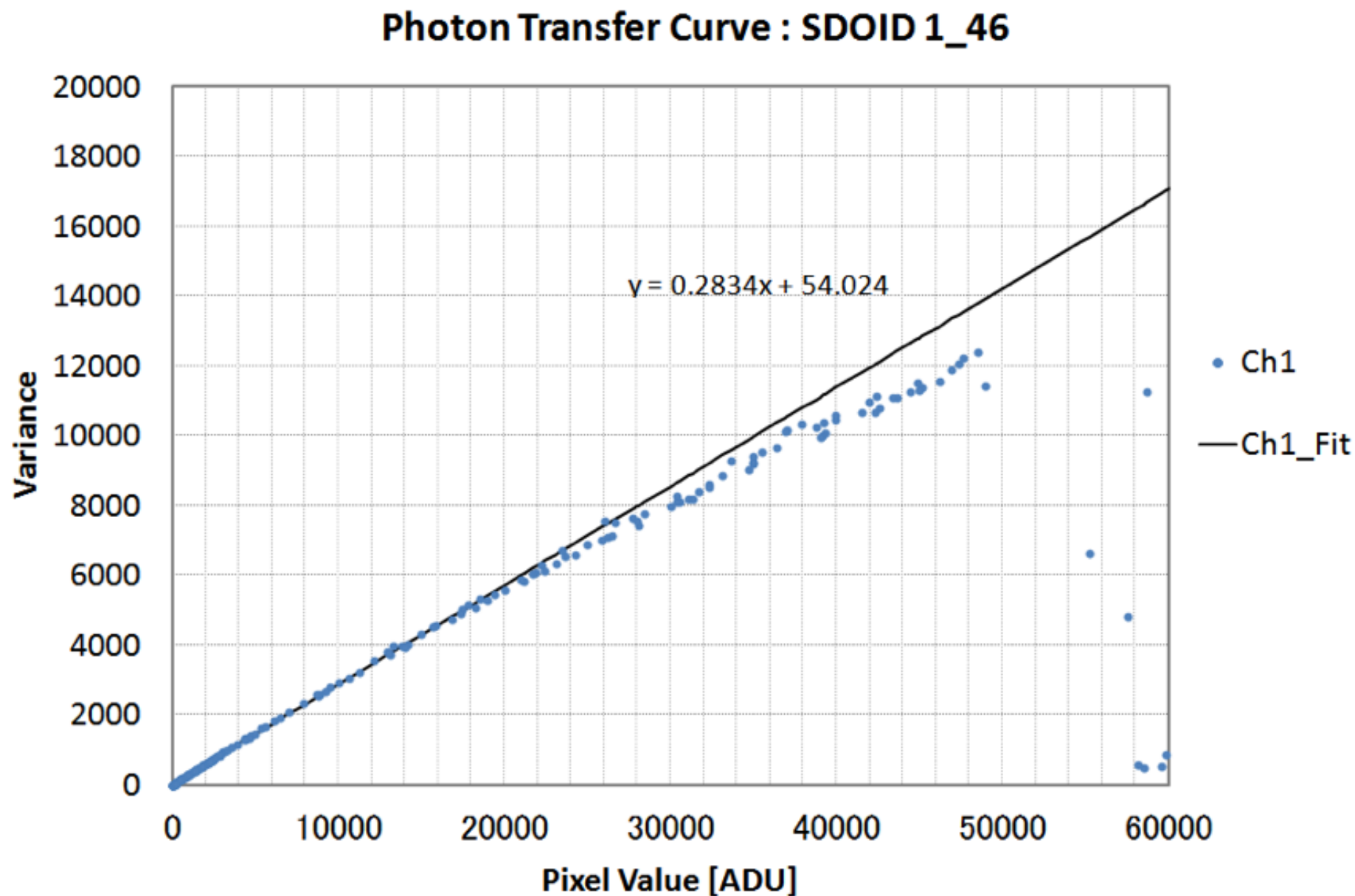
- Developed by Y.Kobayashi
- 1/20 pixel step X-Y stage to measure the pixel response function



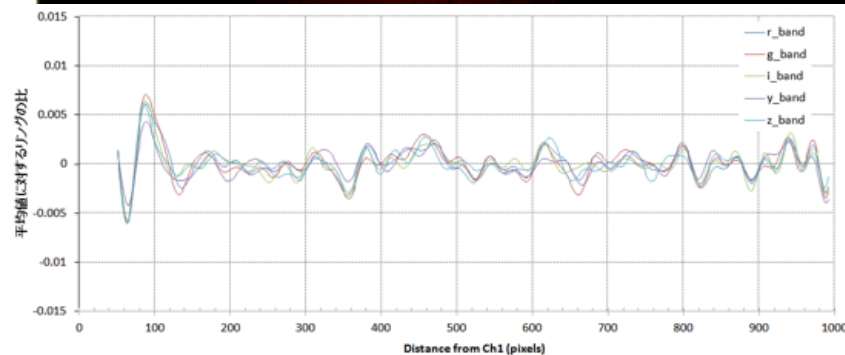
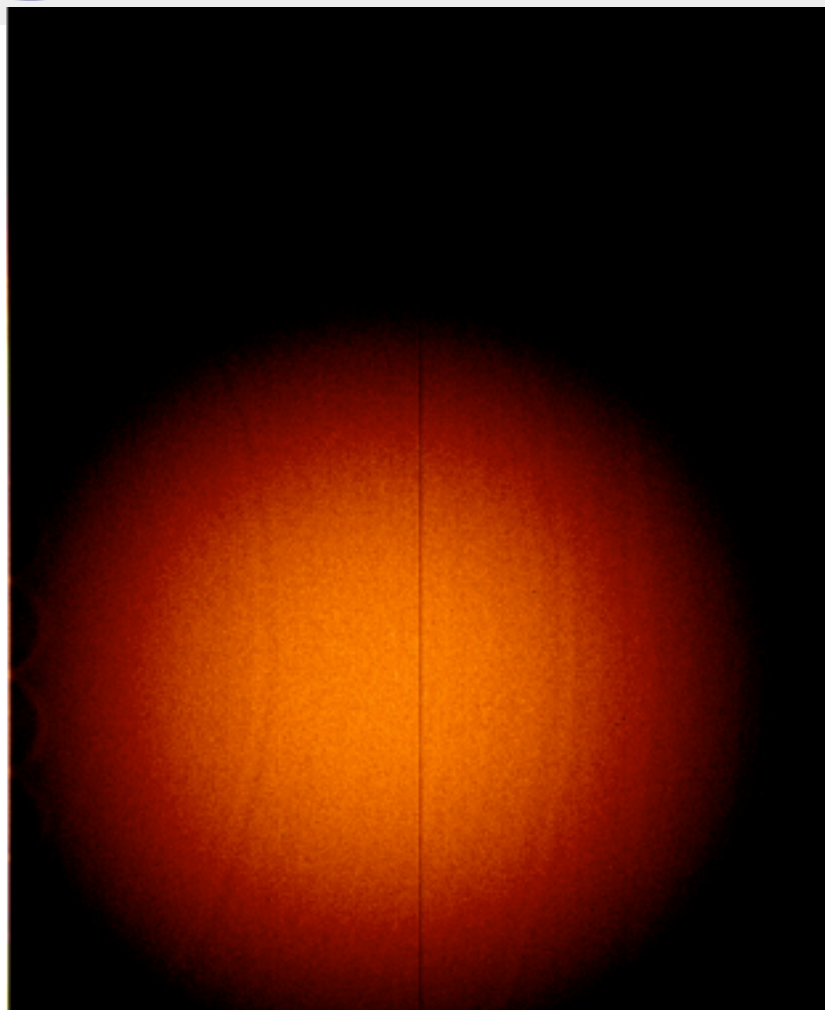
0.95um simulation



Pixel Response Function
(charge diffusion/mobility)
estimated by comparing
the simulation



Tree Ring ?



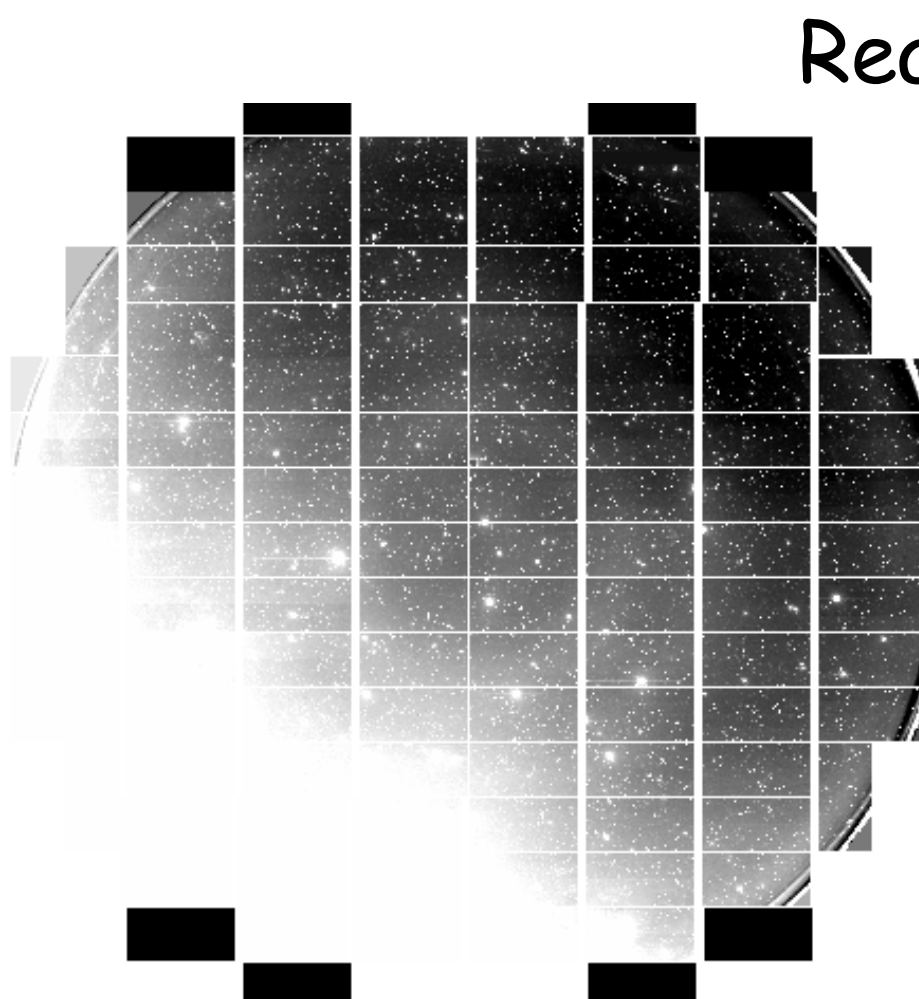
◆ ~0.2 %



MIT/LL CCID20

Other Issues to be settled

(1) Global slope seen on the Dome Flat

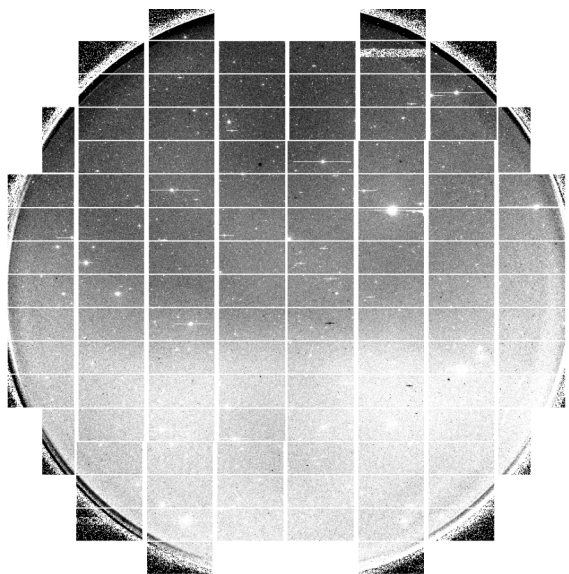


Reached up to 20 %

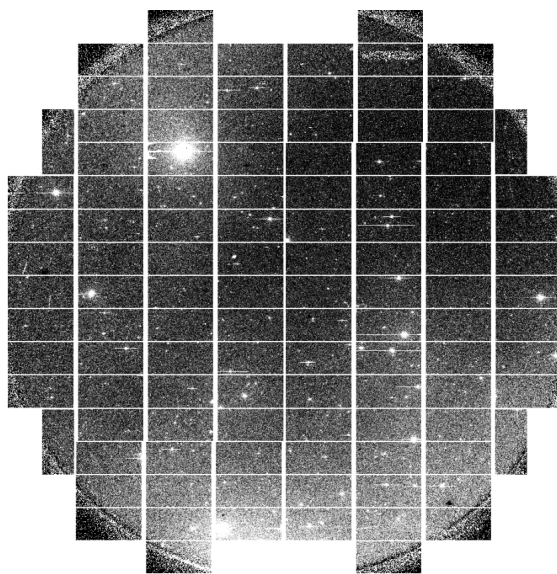
Light Leak ?

This dome flat
cannot be
used for
calibration.

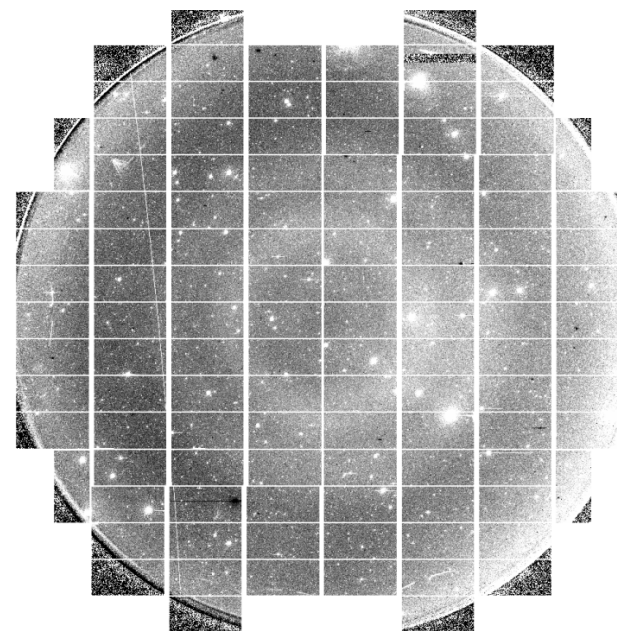
(2) Stray Light



g (5 ~ 6 %)



r (2 %)



i (~2 %)

These are apparently not aperture ghost
but stray light.

Summary

- HSC camera development completed
- Data management software being matured
- In the middle of the commissioning
- 300 nights proposal accepted
- Survey from 2014/02 over 5 years (planned)
- First Public Data Release 2016/02 (planned)
- +++ More careful CCD Characterization and establish the way of the calibration

